University of Alberta

Evaluation of ergonomic risk assessments by quantified means

by

Troy Jones ©

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Abstract

This thesis is a collection of conceptually and scientifically related applied studies examining the properties of observational ergonomic risk assessments. Observational ergonomic risk assessments consider physical exposures related to incidence of musculoskeletal injuries (MSI) in order to prioritize jobs and specific exposures for intervention in prevention initiatives. In the first phase of this project the impact of MSIs on 3 forestry industries was investigated. MSIs accounted for the highest percentage of total time lost and highest percentage of total claims cost in all industries (1997-2002). Total cost of MSI claims exceeded 4.1 million dollars. In the second phase of the project the physical exposures required to perform 4 repetitive sawmill occupations at increased risk of MSI were collected for 99 industrial subjects by quantified means. Rates of repetition observed in the jobs examined ranged from 16 to 34 repetitions per minute. Percentage of maximum voluntary contraction required to perform the primary tasks of the jobs ranged from 9 to 32%. Quantified exposure information allowed investigations of the equivalency of multiple definitions of posture and exertion used interchangeably in ergonomic risk assessments. Significant differences were found between commonly used definitions of posture and exertion indicating the definitions were not equivalent and investigations to assess the impact of variable definition on ergonomic risk assessments were warranted. In the third phase of the project quantified exposure information was used to calculate 5 ergonomic risk assessment techniques by multiple definitions of the exposure variables. Varying definition of posture and exertion variables had a significant effect on all risk assessments examined. Degree of the effect was dependent upon output level and method. Meaningful differences in the output of the risk assessments was observed between workers performing the same job indicating more than one worker assessment is required to arrive at representative job scores. In general the risk output of the risk assessments was not sensitive to difference in reported incidence between facilities examined. Percentage agreement between the risk output of the methods examined ranged from 0 to 100% indicating meaningful variation in risk output scores exists between methods and caution is warranted in application.

Keywords: physical ergonomics, risk assessment, exposure assessment, forest products manufacturing

Dedication:

This work is dedicated to all those who listened to my doubts, inspired my vision, and encouraged my perseverance. I could not have achieved my goal without the support of my loving wife Patricia, my parents Donald and Frances Jones, and my dear friends; Edgar, Inae, Adam, and Pamela. Without the unfaltering guidance of Dr. Shrawan Kumar and generous assistance of Yogesh Narayan none of this would have been possible. Thank you as well to all the industrial subjects and members of the AFPA health and safety committee.

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List of Abbreviations

- Alberta Forest Products Association (AFPA)
- Alberta Human Resources and Employment (AHRE)
- American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV)
- Bureau of Labor Statistics (BLS)
- Canadian Standards Association (CSA)
- Concise exposure index (OCRA)
- Cumulative Trauma Disorder (CTD)
- Dictionary of Occupational Titles (DOT)
- Electromyography (EMG)
- Faculty of Graduate Studies and Research (FGSR)
- Hands Relative to the Body (HARBO)
- Lost Time Claim (LTC)
- Lost Workday Case (LWC)
- Low Back Pain (LBP)
- Lumbar Motion Monitor (LMM)
- Manual Materials Handling (MMH)
- Medical Aid Claim (MA)
- Method for the identification of musculoskeletal stress factors which may have injurious effects (PLIBEL)
- Musculoskeletal Disorders (MSDs)
- Musculoskeletal Injury (MSI)
- National Institute for Occupational Safety and Health (NIOSH)
- National Occupation Classification (NOC)
- National Occupational Research Agenda (NORA)
- Occupational Repetitive Actions index (OCRA)
- Ovako Working posture Analysis System (OWAS)
- Physical Work Stress Index (PWSI)
- Portable Observation Method (PEO)

- Postural and Repetitive Risk factors Index (PRRI)
- Quick Exposure Check (QEC)
- Rapid Entire Body Assessment (REBA)
- Rapid Upper Limb Assessment (RULA)
- Repetitive Strain Injury (RSI)
- Robens Occupational Task Analysis (ROTA)
- Strain Index (SI)
- Upper Extremity (UE)
- Upper Extremity Musculoskeletal Injuries (UEMSI)
- Video technique for the analysis of postures and movements of the head, shoulder and upper arm (VIRA)
- Without Lost Workday (WLW)
- Workers Compensation Board (WCB)

Chapter 1: Introduction

1.1 Foreword

My interest in the work relatedness of musculoskeletal injuries began before I entered the physical therapy program in 1996. During the final year of the physical therapy program, when course options were available, I sought out my future supervisor Dr. Shrawan Kumar and began investigating ergonomic literature in an independent study. Following graduation from the physical therapy program in 2000 I practised physical therapy in the province of British Columbia. I selected British Columbia because of the presence of an ergonomic regulation which required employers to "identify factors in the workplace that may expose workers to a risk of musculoskeletal injury (MSI)" and "when factors that may expose workers to a risk of MSI have been identified employers must ensure that the risk to workers is assessed" (Workers Compensation Board of British Columbia, 1998). The ergonomic regulation in place ensured that where employers had a history of MSI a kinesiologist or physical therapist would be contracted to perform an assessment of the physical exposures of the job(s) in order to identify risks and suggest solutions. My experience performing ergonomic risk assessments left me with questions regarding the validity of the assessment procedures I used. Following approximately 1 year of physical therapy practice I entered the doctoral program at the University of Alberta supervised by Dr. Shrawan Kumar. My doctoral program has been driven toward exploring the validity of ergonomic risk assessments used in MSI prevention initiatives. This thesis is a result of my doctoral studies in Rehabilitation Science (Ergonomics Research Laboratory), Faculty of Rehabilitation Medicine, University of Alberta (UofA).

1.2 Impact of work related musculoskeletal injuries:

The negative impact of work related MSIs on the economies of industrialized countries is well established. In the United States alone the National Research Council estimates musculoskeletal disorders account for nearly 130 million health care encounters annually (National Research Council 2001). Conservative estimates of the economic burden imposed as measured by: compensation costs, lost wages, and lost productivity, are between $45 and 54 billion dollars annually (National Research Council 2001). In Alberta, Canada MSIs continue to account for the highest proportion of Workers Compensation Board (WCB) claims. Within Alberta sprains, strain and tears accounted for 47.6% of all claims in 2005 (Alberta Human Resources and Employment, 2006).

1.3 The relationship between physical exposures and work related musculoskeletal injuries

A large body of evidence supporting the role of physical exposures in the precipitation of MSI is now present. Perhaps the most through review of epidemiologic evidence supporting the role of physical exposures in the precipitation of MSI was performed by the National Institute for Occupational Safety and Health (NIOSH) in 1997 (US Department of Health and Human Services 1997).

In the NIOSH sponsored systematic review of over 600 epidemiological studies a panel of 17 experts found evidence and in some cases strong evidence relating physical exposures to MSIs of the neck, upper extremity, and low back. In most specific conditions the strongest evidence of association was found for the combined role of exposures in MSIs. Given it is the combination of physical exposures that are most strongly related to MSIs a model of causation is needed which is able to account for the relative role of the physical exposures (e.g. force, repetition, posture). Ergonomic risk assessments are based on models of MSI causation which account for the integrated role of physical exposures. It is the primary function of ergonomic risk assessments to identify jobs at an increased risk of MSI. In order to correctly identify jobs at increased risk for MSI the ergonomic risk assessment must consider the relative role of the physical exposures required to perform the job in a valid model of MSI causation. It follows then that the secondary function of a valid ergonomic risk assessment is to identify and prioritize physical exposures for intervention. Observation based ergonomic risk assessments have been identified as the best method, considering the constraints of practice, by which ergonomic practitioners may establish a basis for identifying priorities for intervention (David 2005). Up to 83.1 percent of practicing professional ergonomists make use of observation based ergonomic risk assessments to assess the risk associated with manual materials handling tasks which are the leading source of Workers Compensation Board claims (Dempsey et al. 2005, Dempsey and Hashemi 1999, Murphy et al. 1996).

1.4 Thesis overview

This thesis is divided into 16 chapters and was written in the paper format defined by the Faculty of Graduate Studies and Research (FGSR, 2006). Each chapter in this thesis is a complete study and has been written such that an interpretation of findings is not dependent upon previous or subsequent chapters. Following the series of chapters which constitute a research phase is a brief summary. Phase summaries are provided to clarify how the main findings of each chapter within the phase are related.

Chapter 1 is an introduction to the entire thesis which describes the need for this work and the progression of studies which constitute the thesis. The overall goal of the thesis is to explore the properties of ergonomic risk assessments.

Chapter 2 of the thesis sets the theoretical stage by examining the concepts of primary and secondary prevention as well as the theories of musculoskeletal injury causation. Based upon a review of the subject area it is concluded that valid MSI prediction methods are needed for effective prevention.

In Chapter 3 of the thesis published ergonomic risk assessments are critiqued to identify similarities and differences in the exposure variables considered and the relative role of those exposures in the model of MSI causation upon which the assessments are based. Evidence supporting use of the different methodologies is also presented. Having completed the manuscript constituting the third chapter of the thesis the current state of disagreement between authors of published assessments was clear. Given this disagreement the need to compare and contrast the ergonomic risk assessment methods was highlighted and became the overall goal of the doctoral work. Based on the decision to proceed toward a comparison of ergonomic risk assessments an industrial partner was sought. A review of provincial compensation board documents was performed and the forest products manufacturing industry sector was identified as an appropriate potential industrial partner. The Alberta Forest Products Association (AFPA) which represents four industry groups agreed to participate in the doctoral project. The AFPA is a private, non-profit industry organization. The AFPA represents 60 Alberta companies who manufacture lumber, plywood, pulp and paper and secondary manufactured wood products. AFPA membership forms the province of Alberta's 3rd largest manufacturing sector and employs 54,000 workers throughout Alberta.

1.4.1 Phase 1: Retrospective analysis of Workers Compensation Board data

No information describing occupational injuries and illnesses in the forest products manufacturing industries had been presented in peer reviewed literature prior to beginning the first phase of the doctoral project. Therefore, the first phase of the doctoral work was directed at measuring the impact of MSIs in 3 industries represented by the AFPA. In order to describe the impact of MSIs on the industries a comprehensive WCB database describing all claims occurring in the industries examined occurring from 1997 to 2002 was reviewed. The review examined 3 industry groups and 27 individual companies operating within those industries specifically. Goals of the first phase of the project included: identifying a specific industry and specific at-risk occupations for assessment in the second phase of the project and deriving incidence rate information specific to the occupations examined both within the industry overall and within the companies examined specifically. Chapters 4, 5 and 6 describe the findings of phase 1 of the doctoral project specific to the industries examined (sawmill industry, plywood industry, pulp and paper industry). WCB datasets specific to the 27 companies were also reviewed to measure the impact of MSIs within the companies specifically. Based on the industry and company specific review 4 occupations within 4 companies operating in the sawmill industry were selected for further study in phase two of the doctoral project. Facilities selected for data collection in phase 2 were all of the same approximate size, operated production streams of the same approximate technological level and reported no history of job modifications in the time period from the review to data collection (1997-2005). Studies exploring the occupational injury and illness trends in the forest products manufacturing industries were needed to identify problem trends and direct future health and safety initiatives.

1.4.1.1 Phase 1 objectives

- Identify claims trends in terms of nature of injury, type of accident or exposure, source of injury, and body part injured in three forest products manufacturing industries.
- Determine the effect of work experience and worker age on the above classifications in three forest products manufacturing industries.
- Assess the impact of observed claims trends in terms of cost and duration of claim in three forest products manufacturing industries.
- Identify occupation titles at increased risk of MSI in three forest products manufacturing industries.
- Compare incidence rates of nonfatal injuries resulting in Workers Compensation Board claims in Alberta, Canada in three forest products manufacturing industries to those reported by the Bureau of Labor Statistics in the United States

1.4.2 Phase 2: Collection of physical exposure data

No information was available in the literature describing the physical exposures required to perform the four at-risk sawmill occupations selected prior to phase 2 of the doctoral project. Having identified the four at-risk occupations and body regions for study in the second phase of the doctoral project, preparation for data collection began. The overall goal of collecting physical exposure information from the 4 at-risk occupations was to enable the performance of multiple ergonomic risk assessments. Exposure assessments to be used in the performance of ergonomic risk assessments are typically performed via observation. A body of literature is currently available which describes the significant measurement error resulting from exposure assessment via observation (Bao et al. 2006, Lowe et al. 2004). Inaccuracy resulting from the discrepancy between exposure measurements obtained via observation and actual exposures affect the accuracy of risk assessments in a compound manner (multiple variables considered). The literature base documenting measurement error due to observation suggests accurate risk assessment scores and reliable risk assessment comparisons, to be performed in the third phase of the project, require exposure assessment by quantified means. For this reason objective tools were selected for the exposure assessments performed. Electrogoniometers and surface electromyography were used to quantify the motions/postures and exertions required to perform the at-risk occupations. Because of the quantified nature of the tools used the authors were able to examine the relationship between exposure variable definitions commonly used by workplace evaluators applying ergonomic risk assessment techniques. No literature published prior to the second phase of the doctoral project was available which examined the relationship between exposure variable definitions commonly used in ergonomic risk assessment methods. Studies examining the physical exposures were needed to first enable future risk assessment performance, but also to present the quantified physical exposures associated with a high incidence of upper extremity MSIs and explore the relationship between exposure variable definitions taken to be equivalent by workplace evaluators. During the second phase of the project quantified physical exposure information was collected from 99 sawmill workers performing 4 jobs in 4 sawmill facilities. Chapters 7, 8, 9 and 10 describe the quantified physical exposures obtained and relationship between exposure variable definitions in the 4 at-risk sawmill occupations.

1.4.2.1 Phase 2 objectives

- Describe the physical exposures in a sawmill job with high incidence of upper extremity musculoskeletal injuries by multiple posture, exertion and frequency variable definitions.
- Examine the comparability of those definitions.

1.4.3 Phase 3: Comparison of ergonomic risk assessments

The risk assessment methods compared in this study are: Rapid Upper Limb Assessment (RULA, McAtamney and Corlett 1993), Rapid Entire Body Assessment (REBA, Hignett and McAtamney 2000), the quantitative version of the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV, University of Michigan 2005), the Strain Index (SI Moore et al. 1995), and the Concise Exposure Index (OCRA, Colombini 1998, Grieco 1998, Occhipinti 1998). Risk assessment methods compared in phase three were selected based on semi objective criteria. In order to be considered for inclusion in the studies the risk assessment method must generate an output which may be used to prioritize jobs and problem exposures for intervention. There is presently little literature examining the psychometric properties of ergonomic risk assessments individually and only two studies examining the comparability of multiple risk assessment methods. Due to the lack of literature examining ergonomic risk assessment methods selection of methods to be compared in these studies based on an objective decision matrix was not possible. Methods used in these studies were selected based upon their common use in industrial MSI prevention initiatives.

A literature review performed prior to beginning phase 3 of the doctoral project revealed no studies of the ergonomic risk assessments examined have made use of exposure assessments performed based on objective tools. Additionally, no studies were available which have described the variability in risk assessment output within methods resulting from differences in the exposure profiles between workers performing the same job. Performance of the ergonomic risk assessments based on quantified exposure information was necessary to obtain accurate risk assessment scores and enable valid comparisons. Accurate risk assessment scores enabled the effect of inter-worker variability on risk assessment output to be explored. The exploration of variability is important as it is currently assumed that assessment of a single worker results in a risk assessment score representative of the job. The implication of finding meaningful variability in risk output scores between workers within a job is the requirement of multiple worker assessments.

The literature review performed also revealed no studies which have examined the effect of exposure variable definitions on the ergonomic risk assessments examined. Multiple definitions of the posture and exertion variable considered in an ergonomic risk assessments are available to an evaluator. The implication of meaningful differences in risk assessment scores resulting from varying definitions of posture and exertion is the inappropriate assignment of risk and/or inappropriate identification of problem exposures for intervention.

Consensus among the authors of the risk assessments as to which exposures should be considered and the relative role of the exposures in the causation of musculoskeletal injury has not been reached (Chapter 3). Despite this disagreement several of the risk assessments examined have demonstrated predictive validity (Moore and Garg 1997, Grieco 1998). The implication of disagreement between methods is the inappropriate assignment of risk and/or inappropriate identification of problem exposures for intervention. Studies are needed therefore which compare the results of multiple risk assessment methodologies in the same worker population in order to identify which model of MSI causation is best able to predict morbidity in a given worker population. Only two studies have examined the comparability of multiple ergonomic risk assessments in the same worker population (Bao et al. 2006, Drinkaus et al. 2003). Neither of these studies has made these comparisons based on quantified exposure assessments however. Further, the existing studies were restricted to comparisons of two mutually exclusive methods. Chapters 11, 12, 13 and 14 describe the results of using the quantified physical exposures to calculate the five ergonomic risk assessments examined specific to each at-risk occupation examined. Chapter 15 describes the percentage agreement between the five ergonomic risk assessments examined across all subjects.

1.4.3.1 Phase 3 objectives: Chapters 11-14

- Compare the results of the RULA, REBA, quantified ACGIH TLV for mono-task hand work, Strain Index and OCRA risk assessment methods calculated with quantified physical exposure information.
- Examine the ability of the assessments to differentiate between facilities reporting differing rates of upper extremity musculoskeletal injuries.
- Examine the effect of posture and exertion variable definition on risk assessment output.

1.4.3.2 Phase 3 objectives: Chapter 15

- Examine the agreement between five ergonomic risk assessment methods calculated based on quantitative exposure measures
- Examine the ability of the methods to correctly classify four at-risk jobs.

1.4.4 Discussion and conclusions

Chapter 16 presents a discussion of the findings of the individual chapters within the context of the overall thesis. Finally the conclusions of the overall thesis are discussed as well as future steps.

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Chapter 2 – Physical ergonomics in LBP prevention

A version of this chapter has been published in the Journal of Occupational Rehabilitation.

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2.1 Introduction

With some industries requiring that 50-180 tons of material be moved to produce one ton of marketable product, it is not difficult to accept that back injuries have become among the most expensive work related maladies in industrialized countries (Bullock 1990). The total cost of low back pain (LBP) per year in the United States is commonly estimated to be in excess of 50 billion dollars and as high as 210 billion (Mital 1997, Cooper et al. 1996). Back disorders have been cited as the most expensive health care problem in the 30-50 yr. age group and the leading cause of disability in adults under 45 yrs. of age (Kelsey et al. 1978). In fact up to 80% of the population will have LBP at some point during their working life (Kelsey 1980). In Alberta alone, the cost of new back disability claims totaled $28,132,411 in 1998 (Workers Compensation Board of Alberta 1999). Deyo et al. report LBP to be the second leading cause of work absenteeism in the United States and the most expensive in terms of productivity losses (Deyo and Bass 1989).

Industrialization has lead to an explosion in back injuries and thus compensation dollars awarded. From 1956 to 1976, social security disability awards for back problems increased by nearly 2700% (US Social Security Administration 1979). Considering these statistics, it is clear that low back injuries play a major role in reducing efficiency in the work place. If we accept that back injuries must have a biomechanical basis affected by: force application, effective exposure to force exertion, and the extent and range of motion in these activities, it must be possible to prevent the occurrence of injuries (Kumar 1997).

Driven by the current state of expenditure, industry has developed many different forms of preventative strategies in hopes of minimizing the cost of the LBP problem.

Any program designed to reduce the impact of back injuries must first be sensitive to the occurrence of the causal event(s). Considering for a moment only those back injuries caused by traumatic events, and using an injury triangle as an example, we are able to illustrate the dimensions of workplace injuries. It has been put forth that for every 1 accident resulting in serious injury, 10 minor injuries, 30 accidents resulting only in property damage, and as many as 600 accidents resulting in no injury or property damage occur (Kumar 1997). If these statistics are at all accurate, and we may transfer these estimations specifically to back injuries, with an effective system in place those responsible for safety in the workplace are capable of identifying and correcting the hazard before serious injury results. The shear volume of injuries reported each year illustrates that LBP is currently not being managed in an efficient manner and a change in approach is indicated.

Through examining the main categories of preventative research, and identifying the strengths and weaknesses of each, it is possible to arrive at an ideal system. A system, which utilizes the work place assessment skills of an ergonomist, the musculoskeletal injury causation and treatment knowledge of rehabilitation professionals, and the psychosocial background of qualified industrial psychologists, is needed to effectively combat the occurrence of low back injuries in industry. All these skills are needed to more effectively deal with the occurrence of back injuries in the work place.

In examining the research we find prevention strategies are most often divided into two categories, primary and secondary preventative measures. An effective program must account for both primary and secondary prevention. Primary strategies being those that focus on preventing the event or series of events from occurring and secondary prevention being those programs which focus on keeping the acute occurrence of LBP from progressing to a chronic case. Primary interventions in this area include education programs, workplace fitness programs, employee screening tools, direct measures such as back belts, and primary ergonomic design. In the United States 75% of the total cost of LBP has been attributed to the 5% of the population who are temporarily or permanently disabled (Cooper et al. 1996). It is for this reason that secondary prevention strategies are necessarily included, if not as the main focus, in any comprehensive program. Examples of secondary prevention programs include post incident exercise programs, education programs, ergonomic assessment and redesign, and disability management programs.

With this in mind we must examine the current theories of causation, identified risk factors, and existing measures. In order to arrive at an ideal prevention program designed to optimize productivity, enhance worker morale, and reduce labor turnover, while complying with future regulation.

2.2 Problems interpreting the research

Perhaps necessarily due to complexity, a lack of a definitive definition for "back pain" is noted in the research. More detail is almost universally needed in regards to the type of impairment/disability being experienced, and the specifics in terms of type of occupation or task examined in order to form conclusions upon review of the literature. In addition, we must consider whether or not we are studying a significant enough portion of the subject's time. It is entirely possible that intervention directed at after work activities coinciding with work related education is needed to reduce injuries. Further, it is possible that the lack of previous examination of after work activity cycles is key to the mixed results of certain preventative strategies. We have been, as yet, unable to combine the information gathered in the different areas of study into a model of injury causation, which takes into account the demands a complete day puts on our subject's spine.

We must not discount the individual characteristics of the subject when examining the precipitation of low back injury. Bigos et al. 1991, found job satisfaction to be the single strongest predictor of LBP in an industrial setting, and many other studies have found job satisfaction to be a significant factor in the prediction of LBP as well (Bigo et al. 1991, Lloyd et al. 1979, Andersson et al. 1983, Frymoyer et al. 1985, Marras et al. 1999). We must remember the human form has no average characteristic and that any study is only transferable to the population examined, and further, only in that specific situation. For example, identical tasks performed at different shift times, under different environmental temperatures, or under different lighting conditions place different demands on the worker, thus these additional factors must first be recognized then described and accounted for. These factors may generate stresses not considered in a trial of work site or task. We must always remember the innate complexity of the human being. The variance between individuals is such that precise predictive equations may not ever be developed. However the value of predictive equations in evaluating and designing safety programs in industry cannot be discounted.

Recently ergonomic programs have become a major factor in proposed occupational health and safety legislation in both the United States and Canada. The labor departments of both countries hope that through the development of ergonomic regulation high rates of musculoskeletal injuries in the work force will be brought into check. In the field of ergonomics, however, we must remember that the tools currently being used to evaluate the work place are not perfect; in fact their predictive validity is limited to certain situations. A study by Marras et al. in 1999 examined those tools most commonly used to identify and categorize industrial tasks and found the following (Marras et al. 1999):

- The 1981 National Institute for Occupational Safety and Health (NIOSH) guide correctly identified 91% of the low risk jobs, but 57% of the high risk jobs and 52% of the medium risk jobs were also incorrectly identified as low risk, leaving only 10% of high risk jobs and 43% of the medium risk jobs correctly identified.
- The 1993 NIOSH lifting equation showed a similar pattern in reverse, 73% of the high-risk jobs, 21% of the medium risk jobs and 55% of the low risk jobs were correctly identified. Of particular interest is that 23% of the jobs which had no incidence of back pain (low risk) were incorrectly placed in the high-risk category by this measure.
- The psychophysical measure used by Liberty Mutual, is a measure which categorizes jobs based upon whether or not 75% of the sample females consider the task acceptable. The study found that 60% of the high-risk jobs, 64% of the medium risk jobs, and 91% of the low risk jobs were acceptable to 75%. There was little correlation between risk level and perceived acceptability of the task demonstrated by this measure.

From the results of this research one can clearly determine that in fact the "gold standard" measures we currently use to examine the work environment with are in themselves limited to certain situations, the difficulty of course is knowing which measure to use as this depends on the risk level of the job site. Further, many of these guidelines have arrived at their recommendations for maximum weights etc. through isometric strength testing. It is now clear that job tasks, being primarily dynamic in nature, call for levels of strength not appropriately examined by the guidelines, which were set using isometric strength (i.e. the 1981 NIOSH equation). It has been shown that the maximum strength capability of any worker will vary with posture, velocity of lift, and symmetry of object lifted, none of which are adequately considered by current standards (Kumar 1995). In addition, factors such as mechanical advantage/disadvantage have not been adequately controlled in the research (Kumar 1997). To take a step even further back in the development of standards by which we examine exertion level of tasks and therefore work requirements, it is important to note, that these standards are developed based on a percentage of the subjects aerobic capacity, as determined by leg ergometry. Clearly, values obtained from the analysis of the gross, highly task trained, musculature of the lower extremity is not transferable to an activity requiring the use of mainly the erector spinae and hip extensors as seen in load lifting. Of course, we must keep in mind that these values are those which are easily collected and that one may not ethically accurately determine the maximum aerobic capacity of the spinal support musculature for fear of grievous injury. However, research has shown that the erector spinae fatigue within five minutes with sustained load, a system, which more closely examines the role of the endurance, must therefore be developed (Kumar 1997). Physical ergonomic assessment through an accurate system of guidelines will yield industry the ability to determine the total energy demand of the task. Determining the total demand of a task is important in industry today, as an increasing number of workplace injuries are being attributed to overexertion and repetitive strain.

2.3 What is needed

Research showing causal relationships between fatigue of the active support structures and injury causation cannot be disputed and the statistics support this view. Statistics Canada reported in 1991 that of all compensated injuries, overexertion constituted 48% (Statistics Canada 1991). Research directed at designing new recommendations for maximum allowable intensity of work tasks must be completed.

We must examine more closely the tolerance of the spinal musculature to arrive at these recommendations, in fact, studies examining the exact order of recruitment of the muscles used in lifting and pushing / pulling tasks must be considered. We must also seek to better understand the relationships of the active and passive force couples of the spine. For example many articles in the past have looked at increased intra abdominal pressure as an indication of increasing load on the spine. The exact role of this phenomenon, previously taken as a passive support structure, is now being reexamined.

We must not be discouraged by the inability of one dimension to completely answer the question of LBP. Research with a more multidimensional stance is needed in this area. More studies are needed that examine the effectiveness of programs that include an education, exercise, and an ergonomic component in order that we gain an understanding of the contributions of each. Also direct measures such as back braces, the effectiveness of worker screening programs, and the undeniable role of psychosocial factors, need be further addressed. Studies that are able to examine the role of each factor in a multi-factorial analysis are needed, as many studies are so restricted in scope that their results are made irrelevant to circumstances other than their own.

2.4 Finding the answers

In order to arrive at efficient programs designed to minimize work place back injuries we must first be aware of the currently identified risk factors. There are four categories in which a risk factor may be placed: genetic traits, which are, so far, unalterable and represent the workers predisposition to injury; morphological traits, which are also largely unchangeable and represent the workers vulnerability to injury; psychosocial traits, which may or may not be alterable and represent the workers susceptibility to injury; and lastly, biomechanical aspects, which are alterable, and which we seek to identify and correct through ergonomic recommendations and education regarding technique (Kumar 1999). We must first categorize the identified risk factors before we are able to identify the potential LBP case and prevent its occurrence. Mital 1997 has provided a brief sample of ergonomic risk factors associated with increased risk of back injury, and in some cases described industry standards (Mital 1997). Examples have been included below. A more thorough list of ergonomic risk factors, as identified by Kumar, contributing to work place injuries can be obtained by consulting the reference articles listed (Chaffin 1974, Frymoyer et al. 1980, Andersson 1981, Hagberg 1984, Herberts et al. 1984, Silverstein et al 1986, Westgaard et al. 1986, Heliovaara et al. 1987, Kumar 1990, Kumar 1999).

- Static work - as little as 8% of a muscle's maximum contraction, if sustained, may decrease the blood flow to that muscle. As a result prolonged periods of sustained contraction contribute to injury. As well, due to the visco-elastic nature of collagenous tissue, sustained loads result creep. This lengthening may result in functional instability, also contributing to workplace injury.
- Posture/technique - there is a general misunderstanding of proper lifting technique in industry, determination of the "safest technique" is dependent on the specific situation. Generally, restricting our focus to only the stoop and squat lift technique, when the load is of minimal weight and must be handled repeatedly a stoop posture is recommended. When the load is of moderate weight, can be handled between the knees, and only need be lifted occasionally, a squat posture is recommended (Mital 1997). Loads that cannot fit between the knees and that must be handled repetitively should be handled by two or more people or with the help of equipment (Mital 1997). When two or more people are engaged in a lift, they should be of similar heights and the activity should be coordinated with some form of verbal signal (Mital 1997). General safety points include; avoiding the extremes of range when lifting, turning/twisting, jerky motions, and fixed postures (Mital 1997). Turning/twisting causes the structures supporting the spine to surrender up to 50% of their strength due to the nature of the anatomical structure of the annulus fibrosus which contains the disc. The inter-vertebral discs or more specifically, the annulus fibrosus or ligamentous structure containing the disc, is at-risk when a twist is introduced into the motion. The annulus fibrosus' collagenous structure is arranged such that fibers in one layer are orientated at approximately 120 degrees from those of the adjacent layer. This essentially results in a 50% loss of tensile strength, should a twist be incorporated into the lift. Lifting loads to above shoulder heights and pulling loads should be avoided as well, as disproportionate strain is generated in these positions. If possible, load movement should be limited to between the level of the knee and the

shoulder. It has been found that 66% of lifting tasks start below 31" and that these tasks are associated with 78% of back injuries (Snook et al. 1978). Demand of the task is proportional to the height at which the load is lifted, reach at which it was performed, as well as the magnitude lifted and thus it is important to consider the characteristics of the task as well as the absolute weight (Bullock 1990). Pushing force should be exerted near erect posture, with the handles located approximately 1 meter off the ground (Mital 1997).

- Load characteristics - ideally the load should be rigid, uniform in shape, and should not exceed 50 cm in depth (Mital 1997). In tasks requiring that the object be carried, practical limitations such as the ability to see obstacles should be taken into account. Maximum load should not exceed 50 pounds for males and 44 pounds for females in ideal circumstances according to current guidelines (NIOSH 1991, Mital et al. 1993). Maximum load levels should be adjusted accordingly for factors such as frequency, awkward object size, reach at which lift is performed, etc (Mital 1997). If the load is non uniform, the heavier end should be closer to the body and over the dominant arm and the load's center of gravity offset should be along the line joining the two hands (Mital 1997).
- Handles/coupling - cut out handles should be 11.5 cm long and 2.5-3.8 cm. wide, cylindrical handles should have 3-5 cm clearance all around and should have a pivot angle of 70 degrees from the horizontal axis of the box (Mital 1997). Handles should be located at diagonally opposite ends to provide both horizontal and vertical stability (Mital 1997). The recommended maximum weight should be reduced by up to 15% if the load does not have handles to prevent slipping while pushing, carrying, or pulling (Mital 1997). Additionally, the coefficient of friction between the sole of the shoe and the floor should be at least .3 preferably .5 (Mital 1997).
- Frequency/repetitive handling - it is recommended that load handling be performed no more then 10 times per minute for an 8 hour work period and 12 times per minute if restricted to a 2 hour period (NIOSH 1991).
- Asymmetrical handling/non uniform loads - are a high cause of low back injury. Asymmetrical loads lead to a smaller maximum weight due to increased shear forces, and increased asymmetrical demand on the active and passive support structures of

the spine (Mital 1997). The load must be reduced by 15% if the lift involves a turn of 90 degrees (Mital 1997). The feet should be moving during the performance of this type of task as this reduces stress on the muscles (Mital 1997).

- Space confinement/restraints - if the job requires the load be inserted into a shelf the shelf opening should provide at least 3 cm. additional space for the hands (Mital 1997). If the task requires a stooped posture then 1% should be taken off the maximum load for every degree of spinal flexion (Mital 1997).
- Environment - all relevant safety equipment should be worn, adequate rest realized, and water intake should be observed (Mital 1997).
- Work duration - work load should be reduced as work duration increases (Mital 1997).
- Work organization - proper worker education regarding these factors is essential (Mital 1997).

These are suggestions arrived at by Mital's review of NIOSH guide lines and are meant to serve as examples of a complete list, what is listed above is not a complete list. It is important to note here as well that the following guidelines apply mainly to lifting tasks. Push / pull loads have not been examined. Baril-Gingras & Lortie 1990, found that nearly ½ of all materiel handling activities consisted of push pull activities (Baril-Gingas and Lortie 1990). Statistics Canada 1991 estimated that approximately 20% of all back injuries, due to manual material handling, are due to push/pull activities and that this trend is consistent with those observed in the US and UK (Statistics Canada 1991). Push/pull tasks do take considerably less force than raise/lower tasks however, they are done more frequently, and therefore, contribute significantly to low back injuries as well. In considering these factors, a reduction in demand of the work tasks should be possible. It is important to consider once again that current evaluative measures (i.e. the NIOSH 1981 equation) use static strength testing to set the standards by which job tasks are compared against. We now know that the maximum strength capability of any worker will vary with posture, velocity of lift, and symmetry of object lifted, none of which are adequately considered by current standards (Kumar 1995). Historically standards have been set by testing a group of subjects in a controlled isometric task and then applying these results to various dynamic work situations. As previously stated isometric testing as a criterion for task evaluation is flawed and is at least in part to blame for the limited ability of work tasks designed within ergonomic principles to alleviate injury.

2.5 The new school of thought

Before we look at specific means to prevent injury causation we must first assess how the majority of those injuries are being caused. Recently, more and more focus has fallen on the science of ergonomics and its role in explaining injury causation. The science of ergonomics endeavors to fit the job to the worker by considering how the design of jobs, equipment, and tools may contribute to discomfort, injury, and illness. Further, it is through the science of ergonomics that we develop the tools necessary to understand the demands of work tasks. Through ergonomic assessment aspects such as cumulative load may be assessed. Cumulative load has been indicated as a significant and constant factor in the development of back injury and back pain (Kumar 1994). As previously noted Statistics Canada has reported that the largest proportion of all injuries, 48% are caused by overexertion, resulting in it being a leading cause of work related injury (Statistics Canada 1991). In the United States as well, 25% of all occupational injuries are overexertion injuries and in terms of back injuries 60% are caused by lifting and 20% are caused by push/pull type activities (Deyo and Bass 1989). An overexertion injury is an injury which results when a physical activity exceeds the normal physiological and physical tolerance. The tasks that are at-risk of inducing an overexertion injury are best identified through a physical ergonomic assessment. Many risk factors have been identified as contributing to the accumulation of overexertion. It is important to note that overexertion injuries are not limited to being the result of a one-time stress, but are generally the result of repeated activities without adequate rest. Repeated activities without adequate rest also describes another category of injury increasing in occurrence in the work force, the repetitive strain injury (RSI) or cumulative trauma disorder (CTD). RSI/CTD are those injuries that result from repeated stresses, however minor, which have been applied to the musculotendinous unit. They have been related to the loads of posture, force levels, and repetition of posture and/or force application (Kumar 1999). The etiology of an RSI or CTD is related to any number of factors but is ultimately determined by the characteristics of the muscle and ligamentous tissue itself. Repeated exposure to stress is cumulative due to a property of viscoelastic tissues called hysteresis. The property of hysteresis describes how the amount of relaxation that occurs in a collagenous tissue (tendon, ligament) during the loading phase of a cycle is not equal to that given off during the unloading phase. As a result small-sustained loads may act cumulatively, to yield a lengthening of ligament and tendon through creep. Creep functions to permanently elongate the collagen structure of the tendon and ligament. This stretch may then compress the capillaries within the muscle through the resultant approximation. This deformation may then go onto cause ischemia, tearing of the fibers, and inflammation. When the tendon or ligament has been elongated there is a corresponding increased demand on active control mechanisms in order to maintain stability. When these active mechanisms fatigue a condition of instability may result. If allowed to progress, an RSI can develop into an injury significant enough to cause permanent disability. Some of the factors recognized to cause RSIs or CTDs are: the repetition of small, rapid movements, working in a static and/or awkward posture for long periods of time, insufficient recovery time (i.e. too few rest breaks), poor ergonomic setup of work site, and poor technique in a repetitive activity. The similarities between RSIs and overexertion injuries are many; the main difference between the two is the primary causation. RSIs are by definition the result of repeated tasks, however over exertion injuries are the result of an activity surpassing the ability of the physical structure in question, be it the result of many repeated tasks or a single effort. Clearly, an understanding of the ergonomic principles used to predict and prevent levels of exertion deemed detrimental, as well as an understanding of musculoskeletal injury causation, is needed, if we are to limit the occurrence of these types of injuries and protect the worker.

2.6 Medical knowledge

Teasel and White. 1994, found that for up to 85% of LBP cases a definite pathoanatomic or pathophysiologic diagnosis cannot be made, and that patients with acute back pain and no previous surgical intervention have an 80-90% chance of recovering no matter what treatment they have (Teasell and White 1994). In fact four out of five workers with LBP return to the job within 3 weeks (Snook et al. 1978).

Our current diagnostic imaging techniques exhibit poor specificity. Wiesel et al. 1984, found that upon having a CT scan of the low back, 36% of the asymptotic population under 40 and 50% of the population over 40 demonstrated abnormal results (Wiesel et al. 1984). The effectiveness of diagnostic imaging in the diagnosis of LBP, or screening for predisposition must then be questioned. We must examine how overuse of these techniques is contributing to the cost of LBP compensation, and in addition how this unnecessary utilization of services is translating into increased cost to industry. Teasel and White suggests the focus for examination should move to musculoligamentous testing and away from conventional means (Teasell and White 1994). The view that LBP results from pathology best identified through advanced imaging must be reexamined. It is possible that we may identify more effectively subjects at increased risk by examining the aggravating effects of activity or sustained postures on already injured, but unidentified structures.

If we acknowledge the focus of assessment in the future may be musculoligamentous and musculoskeletal testing, we must then examine the role of the physician in assessing and prescribing the treatment of LBP. Perhaps it would be more cost effective to have another profession, equally familiar with the musculoskeletal system, assessing workers exhibiting LBP, namely the physiotherapist. Studies have found that physiotherapists have been cited far more often than the other health care professionals combined as the practitioners providing the best information about control of injury symptoms (Durant et al. 1989). In addition when appropriately trained, physiotherapists have been shown to be as effective as staff grade surgeons in managing orthopedic patients unlikely to benefit from surgical intervention (Weale and Bannister 1995). Physiotherapy intervention has been shown to have favorable outcome on pain management and sick leave in systematic reviews of randomized controlled trials including patients with LBP, RSIs, foot and shoulder disorders, sports injuries, whiplash injuries, and other orthopedic conditions (Weale and Bannister 1995, Brox et al. 1999, Sandmeier and Renstrom 1997).

The role of appropriately trained medical professionals in an effective program cannot be denied. The importance of a differential diagnosis excluding inflammatory back disease, nonmusculoskeletal causes (i.e. leg length discrepancy, pathology in the pelvis or hip, malignancy, and fracture) and the ability to rule out cord or nerve root compression, particularly in the presence of neurological deficit, must be available in any examination to ensure the workers safety. Arriving at the correct diagnosis combats the occurrence of chronicity, and thus is crucial in minimizing the cost of compensation.

2.7 The Physiotherapist's role

Understanding the development of work related over exertion and RSIs is dependent on a thorough understanding of tissue characteristics and physical performance, this is precisely the area of expertise of a physiotherapist. The physiotherapist brings to bear a significant knowledge of injury causation, the orthopedic assessment skills needed to correctly diagnose the problem, and the treatment skills needed to return the worker to the job with minimal days lost. However, the physiotherapist as he/she exists in the private practice or traditional medical setting is not well versed in the practicality of the work situation. A melding of the physiological understanding, the assessment, and the treatment skills of a physiotherapist with the knowledge of work place assessment and modification of the ergonomist, results in a professional with the knowledge to direct an efficient preventative program. Traditionally, the two disciplines have been separate with the physiotherapist working toward restoring the basic function of the patient necessary to return to the work role and the ergonomist working toward maximizing the efficiency of the worker through the augmentation of external factors. "Commonly patients are released only after partial rehabilitation (barely functional for activities of daily living) and are not followed to their workplaces. Not philosophically but pragmatically it is emphasized the rehabilitation is incomplete unless the patient is reintegrated in the work force with or without adjustment and/or augmentation"(Kumar 1992). The two skill sets, if combined, could work together towards the complete rehabilitation of the worker. This combination of skills may exist today in the form of work place disability management programs. Such programs are currently involved in industry in the United States and the development of such a program is currently underway at the Workers Compensation Board (WCB) of Alberta under the title Progressive Injury Prevention Program. A complete program which effectively deals with musculoskeletal injuries including, but not limited to, LBP involves effectively treating the conditions as early as possible through proactive management programs (Nachemson 1983). Work place disability management programs must include prevention, early assessment, timely rehab, and early return to work (Cooper et al. 1996). Often, in the traditional system too much time has transpired before the proper rehabilitation is begun. This delay causes the worker to lose confidence in his or her ability to carry out those functional tasks required in their respective work situations. The longer these delays occur the more difficult it is to rehabilitate the patient. Currently, it is through disability management programs that the workplace gains the access to the physiotherapist's services in the most effective way. In the future, under the direction of a "physical ergonomist" or physiotherapist knowledgeable in the field of ergonomics, back pain and other musculoskeletal disorders will be more effectively identified, diagnosed, and treated, and these are the necessary steps to forming a proactive prevention program.

A model of injury precipitation must be designed which takes into account the multiple dimensions (physical, psychological and ergonomic) and this model must then be used as a template from which to implement studies. It is only from this type of organized approach it is possible to mount an efficient and well-directed series of studies in hopes of better understanding the role and value of each approach in the solution of the problem. Once better understood it is then possible to evaluate the working population directly, predict injury, and effectively prevent it.

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Chapter 3 – Ergonomic risk assessments: a critique of current tools

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3.1 Introduction and ergonomic relevance

The negative impact of work related musculoskeletal injuries on the economies of industrialized countries has now been well established. In the United States alone the National Research Council estimates musculoskeletal disorders (MSDs) account for nearly 130 million health care encounters annually (National Research Council 2001). Conservative estimates of the economic burden imposed, as measured by compensation costs, lost wages, and lost productivity, are between $45 and 54 billion dollars annually (National Research Council 2001). Clearly the demands imposed by work tasks exceed, in many instances, the capacities of the human system. Currently, within health care systems internationally, there is a movement to require the investigation of job demands for the purpose of assessing the fit between the work performed and the worker. These regulations/guidelines/etc. are commonly termed "ergonomic regulations" and are central to the directed efforts addressing the prevention of work related MSDs. Obviously the central tenet of any effort directed at the identification of levels of risk due to physical exposure must be the assessment of physical demand imposed by the work task(s). The ergonomic risk assessment (ERA) is used for this purpose to assess not only the strength requirements of the occupational task but rates of repetition required, postures required etc.. Quantification of the strength requirements of the occupational task through ERA is a useful in many of the tasks commonly undertaken by the ergonomist. Information quantified through ERA is necessary to effectively implement initial job design, pre-employment worker suitability assessments, musculoskeletal injury prevention efforts, and job redesign following injury. A considerable epidemiologic knowledge base is now present identifying the relationship between physical risk factors and incidence of MSDs. This epidemiologic evidence base may be used indirectly to validate those items defined as modifying risk in ergonomic risk assessment methods which attempt to quantify risk. Experimental evidence has begun to determine the precise mechanisms for this injury category. Although it is not the intent of this paper to describe these mechanisms a presentation of current expert opinion may be found in National Research Council reference published in 2001. Despite the knowledge gained so far, specific cause and effect relationships have not yet been established and precise cut points identifying safe exposure levels have not been determined. An examination of current methods of Ergonomic risk assessment is therefore warranted to describe the peer reviewed methods available.

3.2 Theories of musculoskeletal injury causation

Before an examination of the selected job demands analyses is presented a brief review of the current theories of musculoskeletal injury causation and the state of epidemiologic evidence is indicated. Kumar 2001, has proposed four theories of musculoskeletal injury causation which have been summarized below.

3.2.1 Multivariate interaction theory of musculoskeletal injury precipitation

States that the precipitation of injury is based on the interaction of genetic, morphological, psychophysical and biomechanical factors. Within each of these categories are many variables which potentiate and may affect precipitation of a musculoskeletal injury. Given the sheer number of variations in each of these categories and their interactive effects, the precise mechanisms by which injury may occur are many (Kumar 2001).

3.2.2 Differential fatigue theory

States that occupational injury may result from the mismatch between occupational demands and biological compatibility. This mismatch results in differential loading of active and passive tissues, potentially beyond the range of specific tissue tolerance. This may result in differential fatigue of active structures as well as lengthening of passive structures. Imbalance in load distribution may result in injury (Kumar 2001).

3.3.3 Cumulative load theory

States that biological tissues are viscoelastic. Biological tissues undergo degradation with repeated and prolonged usage due to the cumulative effect of loading precipitating injuries (Kumar 2001).

3.3.4 Overexertion theory

States that a physical exertion of force may exceed the tolerance of the musculoskeletal system or its component parts. Overexertion will be a function of force duration, posture, and motion (Kumar 2001).

3.3 Epidemiologic evidence base

Numerous epidemiologic studies have now been performed examining those physical factors which modify risk of musculoskeletal injury. It is taken that to be valid the Ergonomic risk assessment methods proposed must reflect those factors shown to have a causal relationship in the development of musculoskeletal disorders (MSDs). The term musculoskeletal disorder as defined by the United Sates National Institute for Occupational Safety and Health (NIOSH) refers to conditions that involve the nerves, tendons, muscles and supporting structures of the body (Department of Health and Human Services 1997). In 1997, NIOSH performed a detailed review of over 600 epidemiologic studies examining work-related back pain, tension neck syndrome, shoulder tendonitis, epicondylitis, carpal tunnel syndrome, and hand arm vibration syndrome. This 1997 review concluded that at least moderate evidence has been presented that heavy or forceful work (those tasks requiring significant strength) was related to the low back, neck, elbow and wrist disorders examined (Department of Health and Human Services 1997). Figure 3-1 presents the relative strength of the evidence supporting a cause-effect relationship between high levels of exposure to a physical factor and incidence of a MSD. The variables considered and their discounting factors (or multipliers) in Ergonomic risk assessment methods presented may be indirectly evaluated through comparison of the relative weight of the variable, in the determination of risk, with supporting epidemiologic evidence.

3.4 Ergonomic risk assessment methods

The Ergonomic risk assessment methods presented in the literature may be divided into groups according to the body region of focus, model used, and physical factors considered. Additionally, the occupation group the method was developed to describe, the type of analysis, and the provision of a method to calculate risk are relevant factors. The purpose of the following review is to discuss and compare for consistency the various criteria used to describe physical factors associated with risk of MSD.

3.4.1 General methods

Table 3-1 presents some of the general methods (examining 2 or more body regions) which have been presented in the literature for the purpose of identifying risk of musculoskeletal injury based on the quantification of physical factors.

3.4.1.1 Commentary

All of the methods examined under the general method category follow a model of musculoskeletal injury which states that precipitation of MSI due to physical factors is modulated by the elements of force (strength), posture, repetition and lack of recovery. The general methods examined may be divided into those which propose a method by which risk of musculoskeletal injury may be calculated and those which do not. Those that allow either a direct or indirect assessment of risk of musculoskeletal injury by providing cut points in risk factors assessed include those proposed or described by Hignett and McAtamney 2000, McAtamney and Corlett 1993, Karhu *et al.* 1977, Drury 1987, Chen *et al.* 1989, Corlett *et al.* 1979, Cote Gill and Tunes 1989, and Fransson-Hall *et al.* 1995. The PLIBEL method described by Kemmlert 1995 is not included in the above classification as risk factors identified are dichotomously classified. Dichotomous classification does not facilitate determination of intervention priority nor does it allow rehabilitation programs to reproduce critical job demands by providing detailed information. Those methods proposed or described by Wilktorin *et al.* 1995, Wells *et al.* 1994, Ridd *et al.* 1989, Foreman *et al.* 1988, Holzmann 1982, and Priel 1974 present only methods by which physical factors may be recorded. This examination will be limited to a review of the cut points proposed by the various methods allowing an assessment of risk. Those general methods not allowing either a direct or indirect calculation of risk will not be included as a review of data collection methodology is not the focus of the current paper. Tables 3-2, 3-3, 3-4, and 3-5 summarize the various cut points used by each "general" method examined. The majority of methods described in this section do provide research based justification for the cut points used. The current epidemiologic and experimental evidence base in this area may not allow precise cut points to be determined, however. This difficulty is further compounded by the inability to directly transfer cut points supported by epidemiologic research from one working population to another.

3.4.2 Low-back methods

Table 3-6 presents some of the lower back methods which have been presented in the literature for the purpose of identifying risk of musculoskeletal injury based on the quantification of physical factors.

3.4.2.1 Revised NIOSH equation, Waters et al. 1993

The revised NIOSH equation is a multiplicative model which uses weight constants and modifier variables to arrive at an index of risk. The lifting model is constructed using the same mathematical format developed by Drury and Pfeil 1975. Biomechanical, physiological, and psychophysical data, in addition to expert opinion, is used to determine the weighting of the multiplier variables described. Low frequency lifting (i.e., repetition rates below 4 lifts / min) is limited by biomechanical compression limits at the L5/ S1 level. High frequency limits are based on physiological calculation of energy expenditure using the model proposed by Garg *et al.* 1978. Maximum weight guidelines used in the equation have been set using the psychophysical data presented by Snook 1978 and revised by Snook and Ciriello 1991. Thus, an underlying assumption of the revised NIOSH equation is that the maximum acceptable weight of lift (determined psychophysically) provides an empirical measure that integrates biomechanical and physiologic sources of stress (Karwowski 1983, Karwowski and Ayoub 1984). The NIOSH equation may not be used to determine risk associated with tasks involving: one hand, lifting while sitting or kneeling, lifting in a constrained work space, lifting temperate items, high speed lifting (lifting that is performed in a 2-4 second time frame) lifting wheel barrels, or shoveling are not considered (Waters *et al.* 1993). Additionally, it is assumed that manual handling tasks other than lifting are minimal and do not require significant energy expenditure, especially when repetitive lifting tasks are performed. For this reason the NIOSH assessment procedure may not be well suited to application in non-industrial sectors, given the variability in characteristics of the load lifted, variability in lifting tasks, their frequent association with other handling tasks (trolley pushing or pulling), and finally the presence of other risk factors for the lumbar spine (i.e., whole body vibration) (Grieco *et al.* 1997). Agriculture, transport and delivery of goods, and assistance to individuals who are not self sufficient (at home or in hospital) are typical examples (Grieco *et al.* 1997). In these situations, although the NIOSH lifting index is useful, validated procedures for integrated exposure assessment are not yet available. Use of the 3.4 KiloNewtons (KN) L5/S1 compression limit has been questioned by Leamon *et al.* 1994 based on the variability in observed compression tolerance limits across both epidemiologic and cadaveric studies. Considering the research used in the formation of the 3.4 KN guideline, Leamon *et al.* 1994 suggest that a compression tolerance limit of 5 KN would allow greater discrimination between low and high risk groups. Hidalgo *et al.* 1997 suggests modification of the existing physiologic criteria through consideration of the data presented by Asfour *et al.* 1991 and presents lifting frequency limits based upon task duration. Marras *et al.* 1999 found that only the average weight of box and average horizontal distance multipliers contributed significantly to the revised lifting equation model. The authors suggest that further description of the functional nature of the multipliers may lead to higher predictive ability. Further, upon application of the revised NIOSH equation to a database of 353 industrial jobs it was found that while 73% of the high risk jobs were correctly classified, about 25% of the jobs that had never experienced a back injury were classified as high risk. In addition, over 66% of the medium risk jobs were incorrectly classified as high risk.

3.4.2.2 Lifting model, Hidalgo et al. 1997

The lifting model proposed by Hidalgo *et al.* 1997 is based on the revised NIOSH lifting equation (i.e., it is a multiplicative model with weight constants and modifier variables) with the following modifications. Maximum frequency of lift is calculated with respect to task duration and therefore, the frequency multiplier is calculated considering separately the frequency of lift and the duration of lift. Several additional modifiers are considered in the calculation of the proposed risk index including; age, weight, and heat stress. Age and weight modifiers were developed using the biomechanical data presented by Genaidy *et al.* 1993. The heat stress multiplier is generated from the unpublished work of Havez, 1984. Similar to the NIOSH model, base weights are calculated using the psychophysical data presented by Snook and Ciriello 1991, and modified using the benchmarks established by Tichauer 1978. The authors built and tested the model in two stages, first the model was built using psychophysical data. Secondly, the discounting factors of the various variables were tested and adjusted using physiologic and biomechanical data. Discounting factors relying on physiological data were predicted using the data presented by Garg *et al.* 1978 and modified through consideration of the physiologic fatigue data presented by Asfour *et al.* 1991.

3.4.2.3 Lifting model, Grieco et al. 1997

The lifting model proposed by Grieco *et al.* 1997 is a multiplicative model based on the revised NIOSH lifting equation. Proposed modifications are directed at enabling exposure assessment, associated with manual handling tasks, in Italy. Two discounting factors in addition to those proposed by Waters *et al.* 1993 are described. Guidelines for the manual materials handling activities of pushing, pulling and carrying are also described. One arm lifting is discounted by a factor of .6 and if lifting is carried out by 2 or more operators, always in the same workplace, the weight lifted is divided by the number of operators and discounted by a further factor of .85. Guidelines for the manual materials handling tasks of pushing, pulling and carrying are based solely on the psychophysical data set presented by Snook and Cirello 1991. Comparison of the discounting factors common to the methods proposed by Waters *et al.* 1993, Hidalgo *et* *al.* 1997, and Grieco *et al.* 1997, are presented in figures 3-2, 3-3, 3-4, and 3-5. Multiplier values of the methods compared were interpolated to enable comparison.

3.4.2.4 Manual handling limits for lowering, pushing, pulling, and carrying activities, Shoaf et al. 1997

Shoaf *et al.* 1997 describes a three stage process used in developing a set of multiplicative mathematical models for manual lowering, pushing, pulling and carrying tasks similar to the NIOSH equation. Initially, the psychophysical data set presented by Snook 1978 and Snook and Cirello 1991 was used to generate the multiplier values and recommended load capacities. The base weights generated via psychophysical data, for lowering and carrying, were revised based on Tichauer's 1973 BLE equation to achieve a safe load standard based on the biomechanical integrity of the lower back. It was therefore determined by the authors that maximum acceptable weight of the lowering and carrying tasks (determined psychophysically) provided an empirical measure that integrates biomechanical and physiologic sources of stress (Karwowski and Ayoub 1984). For pushing and pulling, it was determined that because of the short moment arm, the biomechanically derived forces were significantly higher than the psychophysically derived forces. Therefore, guidelines for pushing and pulling exertions determined psychophysically, overestimated capacity of typical working populations. It is concluded by the authors that the hypothesis of Karwowski 1983 and Karwowski and Ayoub 1984 is valid only for tasks in which the compressive forces are critical but is not appropriate for tasks in which the shear forces are critical. Each model's frequency multiplier was tested for feasibility using the Garg 1976 energy expenditure equations and physiological fatigue limits developed by Asfour *et al.* 1991.

3.4.2.5 Low back disorder model using the lumbar motion monitor, Marras et al. 1999

Multiple authors have acknowledged the role of three dimensional velocity and acceleration in the causation of low back injury. The model of low back disorder causation described by this author uses dynamic data recorded by a device utilizing electrogoniometers called the "lumbar motion monitor" (LMM). Using the LMM high risk group membership is predicted (those jobs associated with at least 12 injuries per

200,000 work hours of exposure) in repetitive manual materials handling tasks. Acceleration, velocity and range of motion are calculated in the sagittal, lateral and twisting plane by the LMM. Maximum load moment, frequency of lift, sagittal flexion, twisting velocity, and lateral velocity are inputted into the low back disorder risk model to calculate the percentage likelihood that the job examined would be considered high risk. Likelihood of high risk group membership is based upon data collected by Marras *et al.* 1993 which examined 403 industrial jobs from 48 manufacturing companies. Importantly, this model is limited to jobs involving repetitive tasks and no job rotation. When job rotation requires the worker to perform different tasks daily or weekly the model loses the ability to correctly account for those variables and thus predictive ability is affected. The job analyzed with this system must consist of a few repeatable consistently performed tasks (Marras, 1999). Due to the special emphasis placed on trunk dynamics in this model, which resulted from repetitious jobs without rotation being examined, jobs involving lifting of heavy loads in awkward postures may escape identification (Mirka *et al.* 2000). Maximum duration of data collection may be limited to approximately 30 seconds, and relevant motion at the hip is not recorded (Li and Buckle 1999). Lavender *et al.* 1999, in a comparison of 5 methods for quantifying work related low back disorder risk in production jobs, found the lumbar motion monitor to be the second to the revised NIOSH equation as most likely to categorize jobs as high risk. As a result the authors report that the lumbar motion monitor system is best utilized as a tool to predict injury resulting from cumulative load and not acute risk.

3.4.3 Upper extremity methods

Table 3-7 presents some of the upper extremity methods which have been presented in the literature for the purpose of identifying risk of musculoskeletal injury based on the quantification of physical factors.

3.4.3.1 The strain index, Moore and Garg 1995

"The strain index" described by Moore and Garg 1995 considers multiple risk factors in determining the risk of development of distal upper extremity disorders. Risk factors are classified into 5 categories of increasing risk and a multiplicative model is used to arrive at the final index of risk. The "strain index" is not able to analyze multiple tasks and was not meant to identify risk associated with several specific conditions. Specific conditions the strain index was not meant to assess include: hand-arm vibration syndrome, hypothenar hammer syndrome (mechanical compression of distal upper extremity tissues by extrinsic sources), and disorders of the shoulder, shoulder girdle, neck or back. The physical factors used in the assessment of risk are briefly summarized below. Physiological, biomechanical and epidemiologic models are used to justify values of multiplier variables used. Physiologic equations used in the relative weighting of multiplier values are presented below.

3.4.3.1.1 Physiologic model of localized muscle fatigue

% Maximum strength (MS) = 100 * required strength / Workers maximal strength (task specific) (Moore and Garg 1995)

Endurance time $_{\text{DYNAMIC}}$ (sec) = $324{,}487 / (\%\text{MS})^{2.23}$ (Hagberg 1981)

Endurance time $_{\text{ISOMETRIC}}$ (sec) = $341{,}123 / (\%\text{MS})^{2.14}$ (Hagberg 1981)

3.4.3.1.2 Multipliers

- Intensity of exertion: measured using verbal descriptor similar to the Borg scale estimated by the observer. The multiplier values reflect the rating values (1-5) raised to a power of 1.6. This relationship was selected because 1) the physiological, biomechanical, and epidemiological principles suggest a nonlinear relationship between intensity of exertion and manifestations of strain 2) psychophysical theory suggests that perceived effort is related to applied force by a similar relationship.
- Duration of exertion: calculated by: percentage duration of exertion = average duration of exertion per cycle divided by average exertion cycle time. The corresponding category is then selected and multiplier applied. Multiplier values are determined based on expert opinion.
- Efforts per minute: observed frequency of efforts is categorized and multiplier assigned by scale described. Categories of repetition and multiplier values used are based on expert opinion.
- Hand wrist posture: categorized and multiplier assigned according to scale described. Multiplier values are reported to reflect decreased grip strength and

increased intrinsic stresses to the contents of the flexor and extensor compartments with non neutral postures. Discounting factors (multiplier values) are based on expert opinion.

- Speed of work: categories are correlated to the methods time measurements system and perceived speed determined by the observer. Values are designed to reflect the reduction in maximum voluntary strength as speed increases and the theory that a worker's muscles do not fully relax between high speed, high frequency exertions. Multiplier values are based on expert opinion.
- Duration of task per day: Intended to reflect the beneficial effect of job rotation and the detrimental effects of prolonged activity. Multiplier values are based on expert opinion.

3.4.3.2 Concise exposure index, Occhipinti 1998, Colombini 1998, Grieco 1998

The exposure assessment presented by Occhipinti 1998, Colombini 1998, and Grieco 1998 is based on the calculation of an exposure index similar to the NIOSH lifting equation. Observed values of the variables considered are classified into groups and multiplied with the appropriate discounting factor. The model proposed yields an index resulting from the calculation of the total number of technical actions actually performed during the shift divided by total number of recommended technical actions. Risk of MSD precipitation and recommended action is based on this ratio. The number of recommended actions is based on a constant "action frequency factor" of 30 repetitions per minute and is applied to all regions examined. The action frequency factor is then discounted by the other variables considered (force posture, additional elements, and recovery periods). Recovery periods are assessed firstly through organizational analysis describing task duration and recovery periods both considering natural breaks (i.e., lunch) and in relation to control actions (considered recovery periods) and mechanical actions (considered repetitive periods).

3.4.3.2.1 Multipliers

- Repetitiveness/frequency: calculation of the total number of recommended technical actions per shift is a product of the interaction of all variables considered.

- Force: The CR-10 Rating of perceived exertion described by Borg 1982, is used to quantify effort or force. Collection of data and assignment of the appropriate force score is accomplished by observing the full cycle and then asking the worker to rate each relevant action within the cycle. The relative duration of each action within the cycle is then calculated and multiplied with the appropriate discounting factor. All actions requiring a significant level of force are then summed to yield the force score.
- Posture and types of movements: Postures of the hand, wrist, elbow and shoulder are described in relation to the static and dynamic movements exceeding or falling below a critical angle. Posture scores are further modified with respect to type, duration held, and type of movement (static or dynamic). Increased risk scores are therefore associated with posture in relation to articular range or grip type, duration of time spent in the posture, and lack of variation in the cycle.
- Additional factors: Risk in relation to additional factors is assessed through dichotomous classification of the presence of the factor and the percentage of the cycle time present (e.g. 1/3, 2/3, 3/3).

3.4.3.2.2 Work breaks and duration of recovery periods

Dynamic activity: Calculation of risk is based on the Victorian Occupational HSC Draft code of practice 1988, in relation to occupational overuse syndromes. Within this Australian document the authors report that a work rest ratio of 5:1 is recommended. The analysis model used for calculating risk in dynamic activities associated with inadequate rest is based on this 5:1 work rest interval criterion. In the procedure proposed, the daily job activities are examined and the work rest interval calculated. Increasing risk is associated with higher proportions of work compared with rest and the number of hours daily with insufficient rest or in potential overload.

Static activity: The levels of contraction force, there RPE equivalent, required recovery period and percentage recovery are presented in table 3-8.

3.4.3.3 Exposure scale, Genaidy et al. 1993

Genaidy et al. 1993 describes a method of determining risk of upper extremity and neck MSD based on the determination of daily action and maximum permissible limits for the neck and upper extremity. The maximum permissible limit is defined as 3 times the action limit for each region considered. Guidelines given are based on epidemiologic criteria for repetition and posture. For force limits, biomechanical data are used to describe the action limit and epidemiologic data to describe the maximum permissible limit. Calculation of "the ergonomic stress index" considers the physical factors of repetition, force, and posture individually and interactively. The effect of physical factors individually as well as the interaction between factors is equally weighted in the calculation. Based on the value of the physical factor observed a numerical value, reflecting level of risk, is assigned. Repetition categories are assigned by classifying the number of observed repetitions per day. Force is assigned through calculation of force as a percentage of maximum voluntary contraction. Posture is reported as a percentage of the total range of motion.

3.4.3.4 Additional methods

Additional methods described by Keyserling et al. 1993, Li and Buckle 1998, and James et al. 1997 determine risk based on categorization of observed physical factors. The methods proposed by Keyserling et al. 1993, Keyserling 1986, Kilbom et al. 1986, and James et al. 1997 imply increased risk with increasing levels of the physical factors examined, however do not supply a method of risk calculation. The "quick exposure check" described by Li and Buckle 1998 does describe a method of calculating risk based on the categorization of physical factors observed. The system described by Latko et al. 1997 is an observational scale, in which repetition or hand activity is characterized using a visual analog scale ranging form the lowest to the highest amount imaginable. No method of risk quantification is described by Latko et al. 1997. The presence of scales capable of characterizing force, posture and mechanical stresses are reported in Latko et al 1999, however these scales have not been presented (59). Tables 3-9, 3-10, 3-11, and 3-12 present the cut points used in determining risk by the upper extremity methods examined.

3.5 Summary and conclusions

Further research is needed describing the interactive effects of the multiplier variables used in all methods proposed thus far. Further, epidemiologic studies examining the relative role of each risk factor category (e.g. force, repetition, posture, recovery) in the risk of musculoskeletal injury precipitation specific to each body region are needed. Commonly values used in the calculation of risk as multipliers or constants are extrapolated from epidemiologic studies specific to worker population and body region and applied universally. This approach, while arguably necessary in facilitating proactive injury control and disability management efforts, is not valid. Studies examining the ability of methods to identify high risk jobs based on previous claims experience are present only for those methods examining the low-back. Comparison studies examining general and upper extremity methods are also needed.

Currently there is little consistency between either the cut points used or method of risk calculation in Ergonomic risk assessment methods described in the scientific literature. Significant limitations exist in all methods described. These issues need to be conclusively resolved and validated. Determination of the most appropriate method for industrial application requires careful consideration of factors including: the industrial population for which the method has been developed for, body region(s) considered, and the mechanism(s) of injury accounted for.

Table 3-1: General physical demands analysis methods examined

Method	Body regions examined	Physical factors examined	Occupation Group	Calculation of risk	Static or dynamic analysis
Hignett and McAtamney 2000. REBA (Rapid entire body assessment)	• Trunk • Neck • Legs • Upper arms • Lower arms • Wrists	• Posture • Force • Coupling	Health care industry	Yes	Dynamic
McAtamney and Corlett 1993. RULA (Rapid upper limb assessment)	• Upper arm • Lower arm • Wrist • Neck • Trunk • Leg	• Posture • Force • Repetition	Data processing operations, sewing machine operations, production line packing, brick sorting and wire twisting.	Yes	Dynamic
Karhu et al. 1977. OWAS (Ovako Working posture analysis system)	• Head and neck • Trunk • Upper limbs • Lower limbs	• Posture • Force	Steel, textiles, meat, mining, wood and light metal industries	Yes	Static
Drury 1987. ERA method	• Neck • Back • Shoulder • Elbow • Forearm • Wrist	• Force (grip type) • Postural discomfort • Posture • Repetition	Shoe industry	No	Dynamic
Foreman et al. 1988. ERA method	• Whole body posture (e.g., Stand, stoop, squat, walk, sit)	• Activity • Posture • Frequency and duration of activities	Health care industry (Nurses)	No	Dynamic
Chen et al. 1989. PWSI (Physical work stress index)	• Overall physiological stress	• Movement (location) • Orientation • Base posture • Hand position • external work load • Load due to imposed accelerations, • Thermal environment	Lifting task, hand tool task, light assembly task.	Yes	Dynamic
Priel 1974. ERA method	• Head • Shoulder • Arms • Forearms • Trunk • Thighs • Legs • Feet	• Posture	General working postures	No	Dynamic
Corlett et al. 1979. Posture targeting	• Head • Neck • Shoulder • Trunk • Wrist • Hip • Knee • Ankle	• Posture • Manual activity performed	Static posture (slides) of machine operators in the electronics industry	Yes	Dynamic

Ridd et al. 1989. ROTA (Robens occupational task analysis system)	• Undefined (description of a system which may be used with dedicated posture/activity libraries.	• Posture • Repetition • Force • Environment • Workstation	General	No	Dynamic
Kemmlert 1995. PLIBEL (Method for the identification of musculoskeletal stress factors which may have injurious effects)	• Neck/shoulders, upper part of back • Elbows, forearms, hands • Feet • Knees and hips • Low back	• Dichotomous, general ergonomic risk factor identification	Multiple work groups including; small enterprise, furniture manufacturing, construction, data terminals, farming	Yes	Dynamic
Wells et al. 1994. ERA method	• Hand • Wrist • Shoulder • Back	• Posture • Force through EMG (static, dynamic and peak)	Car seat cover manufacturers and electrical panel manufacturers	No	Dynamic
Cote-Gill and Tunes 1989. ERA method	• Head • Forearm • Trunk • Thigh • Knee • Ankle	• Sitting posture	Seated subjects undergoing classroom activities,	No	Dynamic
Wilktorin et al. 1995. HARBO (Hands relative to the body)	• Whole body posture	• Posture of the hands relative to the body.	Ceiling builder, carpet layer, railway track layer, car assembly worker	No	Dynamic
Fransson-Hall et al. 1995. PEO (portable observation method)	• Hand • Neck • Trunk • Knee	• Posture • Force	Cook, secretary, mechanic, furniture mover	No	Dynamic
Holzmann 1982. ARBAN	• Head-neck • Shoulder-arm • Trunk and Back • Leg	• Posture • Force • Static load • Vibration • Psychophysical demand	Methodology presented only	No	Dynamic

Table 3-2: Posture cut points used to identify risk of musculoskeletal injury by method

Body region	**Hignett and McAtamney 2000**	**McAtamney and Corlett 1993**	**Karhu et al. 1977**	**Drury 1987***	**Corlett et al. 1979**	**Cote-Gill and Tunes 1989**	**Fransson-Hall et al. 1995**
Hand/wrist	- 0-15° of flexion or extension - > 15° of flexion or extension Increased risk if wrists are deviated or twisted	- Neutral - Flexion or extension 0-15° - Flexion or extension > 15° Increased risk for any radial or ulnar deviation	Category not applicable	Flexion; 0-9,9-23, 23-45, 45+ Extension; 0-10, 10-25, 25-50, 50+ Radial deviation; 0-3, 3-7, 7-14, 14+ Ulnar deviation; 0-5, 5-12, 12-24, 24+	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	Category not applicable	Below shoulder level Above shoulder level
Forearm	Category not applicable	- "mid range of twist" - "at or near end range of twist"	Category not applicable	Pronation; 0-8, 8-19, 19-39, 39+ Supination; 0-11, 11-28, 28-57, 57+	Category not applicable	- Supported - Unsupported	Category not applicable
Elbow	Lower arm: - 60-100° of flexion - < 60° flexion or >100° flexion	- 60-100° of flexion - <60° or > 100° flexion Increased risk if working across the midline or out to the side	Category not applicable	Flexion; 0-14, 14-36, 36-71, 71+	Category not applicable	Category not applicable	Category not applicable
Shoulder	Upper arm: - 20° extension to 20° flexion - > 20° extension 25-45° of flexion - 45-90° of flexion - > 90° flexion Increased risk if arm is: abducted or rotated or if shoulder is raised Decreased risk if leaning	- 20°Flexion to 20° degrees extension - Flexion 20-45° or Extension > 20° - Flexion 45-90° - Flexion >90° Increased risk if; shoulder is elevated or if upper arm is abducted Decreased risk if the operator is leaning or the	- < 90° shoulder flexion - Both arms .90° shoulder flexion - One arm > 90° flexion	Outward rotation; 0-3, 3-9, 9-17, 17+ Inward rotation; 0-10, 10-24, 24-49, 49+ Abduction; 0-13, 13-34, 34-67, 67+	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	Recorded in 15° increments from 60° extension to 90° flexion	Category not applicable

	supporting weight of arm or if posture is gravity assisted)	weight of the arm is supported		Adduction; 0-5, 5-12, 12-24, 24+ Flexion; 0-19, 19-47, 47-94, 94+ Extension; 0-6, 6-15, 15-31, 31+			
Neck	- 0-20° flexion -> 20° flexion or in extension Increased risk if twisting or side flexed	- 0-10° flexion - 10-20° flexion - 20+° flexion - Any extension Increased risk if side bent or twisted	- 0° flex/ext, 0° rot, 0° side flexion -> 30° flexion -> 30° lateral flexion -> 45° of rotation -> 30° extension	Rotation; 0-8, 8-20, 20-40, 40+ Lateral bend; 0-5, 5-12, 12-24, 24+ Flexion; 0-6, 6-15, 15-30, 30+ Extension; 0-9, 9-22, 22-45, 45+	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	- Forward bent - Neutral position - Backward bent	- Flexion > 20 degrees - Rotation > 45 degrees
Trunk	- Upright - 0-20° flexion or extension - 20-60° flexion or >20° extension -> 60° flexion Increased risk if twisting or side flexed	- Sitting supported with hip/trunk angle of >90° - 0-20° flexion - 20-60° flexion -> 60° flexion Increased risk if side bent or twisted	- 0° flex/ext, 0° rot, 0° side flexion - Rotation and lateral flexion (undefined rotation or lateral flexion angle) - 20-30° of axial twisting (undefined rotation angle) - 20-30° forward flexion (undefined hip flexion/lumbar flexion angles)	Rotation; 0-10, 10-25, 25-45, 45+ Lateral bend; 0-5, 5-10, 10-20, 20+ Flexion; 0-10, 10-25, 25-45, 45+ Extension; 0-5, 5-10, 10-20, 20+	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	Recorded in 15° increments from 60° extension to 90° flexion	- Flexion 20-60° - Flexion > 60° - Rotation > 45°
Hip	Legs: - Bilateral weight bearing walking or sitting	Leg posture: Legs & feet well supported with weight borne evenly	Lower limbs: - Standing on one leg (knee straight) with other off the floor.	Category not applicable	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	Angle between the trunk and the thigh is recorded in 15° increments from 135 to 30°	Category not applicable

	- Unilateral weight bearing, feather weight bearing or an unstable posture Increased risk if knee(s) are between 30 and 60^0 of flexion Increased risk if knee(s) are > 60^0 flexion (not for sitting)	OR If standing with body wt even on both feet and room for position change Increased risk if legs and feet are not supported or weight is unevenly balanced	- Standing with knees fully extended -Generally normal seated posture				
Knee	Category not applicable	Category not applicable	Category not applicable	Category not applicable	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	Angle between the trunk and the thigh is recorded in 15^0 increments from 135 to 0^0 - Crossed (adducted across midline) - Uncrossed	Category not applicable
Ankle	Category not applicable	Category not applicable	Category not applicable	Category not applicable	Posture is recorded in 1 degree increments for joint movements in the sagittal or frontal plane	- Crossed (adducted across midline) - Uncrossed	Category not applicable

Note: In general increased risk is associated with descending categories
*Note: postural ranges are given in % of maximal range per joint. Risk increases as % range increases.

Table 3-3: Repetition/frequency (including determination of static posture) cut points used to identify risk of musculoskeletal injury by method

Author(s):	**McAtamney and Corlett 1993**	**Drury 1987**
Description	One point is added to the risk calculation if the task is mainly static (held for more than 1 min) or is repeated more than 4 times per min.	Frequency of movements constituting a risk factor are not described

Table 3-4: Force cut points used to identify risk of musculoskeletal injury by method

Author(s):	**Hignett and McAtamney 2000**	**McAtamney and Corlett 1993**	**Karhu et al. 1977**	**Drury 1987***	**Chen et al. 1989****	**Corlett et al. 1979*****	**Fransson-Hall et al. 1995**
Manual Handling / undefined	- < 5 kg. - 5-10 kg. - > 10 kg. Increased risk if there is shock or rapid build up of force	- No resistance or less than 2kg. intermittent load or force - 2-10 kg. intermittent load or force - 2-10 kg. Static load or repeated load or force - 10 kg. or more static load or 10kg or more repeated loads or forces or shock or forces with rapid build up	- Less than 10 kg. - Between 10 and 20 kg. - Greater than 20 kg.	Grip type: - Power grip - Finger tip pinch - Pulp pinch - Lateral pinch	External load: - 0 - 0.5 kg - 0.5 kg – 5 kg. - 5 kg. - 10-20 kg. Acceleration: - Zero - Slight - Moderate - Heavy	Manual activities: crank, strike, push, pull, hold, squeeze, twist, and wipe Weight of object.	Manual handling: - 1-5 kg. - 6-15 kg. - 16-45 kg. - > 45 kg. - unknown force

* Note: Increasing levels of risk during grip are not clearly identified, forces are measured for each grip

** Note: Force required to perform task is a variable in the calculation of physiologic load.

*** Note: Force required may be indirectly determined via activity variables marked dichotomously and weight recorded.

Table 3-5: Additional factors, description and cut points used to identify risk of musculoskeletal injury by method

Author(s)	**Hignett and McAtamney 2000**	**Drury 1987**	**Chen et al. 1989**
Description	Activity score is used to modify risk (elevate) if any of the following are observed; - 1 or more body parts are static (held for longer than 1 minute) - Action causes rapid large range changes in posture or an unstable base. - Repeated small range actions, e.g. repeated more than 4 times per minute (not including walking) Coupling modifier is used to elevate risk any of the following are observed; - Hand hold acceptable but not ideal or coupling is acceptable via another part of the body - Hand hold not acceptable although possible - Awkward, unsafe grip, no handles - Coupling is unacceptable using other parts of the body.	Postural discomfort is assessed psychophysically using the body discomfort scale (21) and the general discomfort scale (22).	Additional factors considered are; movement (location), orientation, base posture, hand position, external work load, load due to imposed accelerations, and thermal environment. Hand orientation is given relative to the "box" bordered superiorly, laterally, and distally by the arms when the shoulders are flexed to 90°, and the level of the waist inferiorly. Left and right hand position are recorded relative to the "box" in four categories. - In box - Edge of box - Outside of box - Outside of box in two planes Location (movement) of the worker is recorded relative to the work station in four categories: - Primary work space - Meters from primary workplace: 5-10m. - Meters from primary work place; 10-50m - Meters from primary work place: >50m Orientation of the worker is recorded in relation to the primary work place in four categories: - Forward - Right - Left - Backward Thermal load is recorded in relation to four categories: - 20-25° C - 25-30° or 15-20° C - 30-35° or 0-15° - > 35° or < 0° Postural base is recorded in relation to four categories: - Lying - Sitting - Leaning - Standing

Table 3-6: Low back physical demands analysis methods examined

Method	Physical factors examined	Tasks considered	Calculation of risk	Single and/or multitask assessment
Waters et al. 1993 Revised NIOSH equation	• Frequency multiplier • Coupling multiplier • Asymmetric multiplier • Distance multiplier • Vertical Multiplier • Horizontal multiplier • Load constant	Lifting	Yes	Single and multitask
Grieco et al. 1997 ERA method	• Vertical multiplier • Displacement modifier • Horizontal multiplier • Asymmetrical multiplier • Coupling multiplier • Frequency multiplier • Variable load constant	Lifting, pushing, pulling, carrying	Yes	Single task
Hidalgo et al. 1997 ERA method	• Horizontal multiplier • Vertical distance at origin multiplier • Vertical travel multiplier • Lifting frequency multiplier • Task duration multiplier • Twisting angle multiplier • Coupling multiplier • Heat stress multiplier • Age multiplier • Body weight multiplier • Variable load constant	Lifting	Yes	Single task
Shoaf et al. 1997 ERA method	• Carrying; frequency, traveled distance, vertical height • Lowering; frequency, horizontal distance, vertical distance • Pushing; frequency, traveled distance, vertical height, • Pulling; frequency, traveled distance, vertical height, • Age, body weight, and task duration multiplier • Variable load constant	Push, pull, lower, carry	Methodology presented only.	Single task
Marras et al. 2000 Low back disorder risk model	• Maximum load moment • Maximum lateral velocity • Average twisting velocity • Lifting frequency • Maximum sagittal trunk angle	Lift	Yes	Single task

Table 3-7: Upper extremity methods examined

Method	Body regions examined	Physical factors examined	Occupation group	Calculation of risk	Static or dynamic	Additional factors examined
Colombini 1998 Occhipinti 1998 Grieco 1998 OCRA (concise exposure index)	• Shoulder • Elbow • Hand/Wrist	• Force • Posture • Repetition • Lack of recovery • Additional factors:	Manufacturing industries; ceramics, timber, automotive, meat and vegetable processing, tellers	Yes	Dynamic	Vibration, velocity and acceleration, precision, localized compression, exposure to cold, use of gloves, coupling, wrenching movements, return shock
Moore and Garg 1995 The strain index	• Hand/wrist	• Intensity of exertion • Duration of exertion • Efforts per minute • Hand/wrist posture • Speed of work • Duration per day	Pork processing, turkey processing, chair manufacturing	Yes	Dynamic	Category not applicable
Keyserling et al. 1993 ERA method	• Hand/wrist • Shoulder	• Repetitiveness • Forceful manual exertions • Awkward postures and hand tool usage	Metal plant, engine plant, parts distribution warehouse.	Yes	Dynamic	Local mechanical contact stress, gloves, vibration, decreased temperature
Keyserling 1986 ERA method	• Trunk • Shoulder	• Posture	Automobile assembly	No	Dynamic	Category not applicable
Kilbom et al. 1986 VIRA. (Video technique for the analysis of postures and movements of the head, shoulder and upper arm).	• Head • Shoulder • Upper arm	• Posture • Subjective discomfort	Electronics manufacturing industry	No	Dynamic	Subjective rating of discomfort
James et al. 1997 PRRI	• Neck • Shoulder • Elbow • Wrist	• Static contraction • Repetition • Posture	VDT use (banking industry)	Yes	Dynamic	Category not applicable

(postural and repetitive risk factors index).						
Li and Buckle 1998 QEC (Quick exposure check)	• Back • Shoulder/arm • Wrist/hand	• Frequency • Posture • Force	Undefined "practical tasks", manual assembly (bolting), manual materials handling (lifting) and VDU work, simulated nursing tasks.	Yes	Dynamic	Vibration, visual demand, work pace, stress
Genaidy et al. 1993	• Fingers • Wrist • Elbow/shoulder/neck	• Repetition • Force • Posture	Methodology presented only.	Yes	Dynamic	Category not applicable
Latko et al. 1997	• Fingers • Wrist	• Repetition	Office furniture, spark plug and container, automotive components, manufacturing industries	No	Dynamic	Force, posture and localized mechanical stress scales reported as present but not described

Table 3-8: Calculation of recovery periods (in seconds) for operations requiring isometric contractions (equal to or longer then 20s) for applied times and forces

Force (Borg scale)	**Time held (sec)**	**Recovery period (sec)**	**Percentage recovery (sec)**
Up to 2 (20% MCV)	20	2	10
	30	3	10
	45	7	15
	120	60	50
	180	180	100
	240	480	200
	300	1200	400
	450	2700	600
About 3 (30%MCV)	20	10	50
	40	40	100
	60	120	200
	90	360	400
	120	720	600
	150	1200	800
About 4 (40% MCV)	20	20	100
	30	60	200
	50	200	400
	70	420	600
	90	720	800
Circa 5 (50% MCV)	20	40	50
	30	120	400
	40	240	600

Adapted from Colombini 1998.

Table 3-9: Posture cut points used to identify risk of musculoskeletal injury by method

Body region	**Colombini 1998 Occhipinti 1998 Grieco 1998**	**Moore, and Garg 1995**	**Keyserling 1986**	**Kilbom et al. 1986**	**James et al. 1997**	**Li and Buckle 1998**	**Genaidy et al. 1993***
Hand/wrist	Extension: > 45^0 Flexion: > 45^0 Radial deviation: > 15^0 Ulnar deviation: > 20^0	Extension: - 0-10^0 - 11-25^0 - 26-40^0 - 41-55^0 - > 60^0 Flexion: - 0-5^0 - 6-15^0 - 16-30^0 - 31-50^0 - > 50^0 Ulnar deviation: - 0-10^0 - 11-15^0 - 16-20^0 - 21-25^0 - > 25^0	Category not applicable	Category not applicable	- Flexion/extension angles < 20^0 - Flexion/extension angles > 20^0 - Radial/ulnar deviation angles < 20^0 - Radial/ulnar deviation angles > 20^0	Almost a straight wrist Deviated or bent wrist position	0-5% 6-10% 11-20% 21-30% 31%+
Elbow	Supination: > 60^0 Pronation: > 60^0 Flexion/extension range: > 60^0	Category not applicable	Category not applicable	Category not applicable	- Angle maintained between 60 and 90^0 of flexion - Angle of flexion beyond ideal range	Category not applicable	0-5% 6-10% 11-20% 21-30% 31%+
Shoulder	Abduction: > 45^0 Flexion: > 80^0 Extension: > 20^0	Category not applicable	Standard shoulder postures: (flexion/abduction) - Neutral ($\leq 45^0$) - Mild flexion/abdutction($45 < \text{to} \leq 90$ degrees) - Severe Flexion/abduction (> 90 degrees)	Abduction - 0-30^0 - 30-60^0 60-90^0 > 90^0 Flexion: 0-30^0 30-60^0 > 60^0	- Shoulder flexion < 30^0 - Shoulder flexion > 30^0 Maintained shoulder flexion < 45^0 Maintained shoulder flexion > 45^0	Shoulder / arm: - At or below waist height? - About chest height - At or above shoulder height?	0-5% 6-10% 11-20% 21-30% 31%+

				Extension: $> 0^{0}$			
Neck	Category not applicable	Category not applicable	Category not applicable	- $0\text{-}20^{0}$ - $> 20^{0}$	Category not applicable	Category not applicable	0-5% 6-10% 11-20% 21-30% 31%+
Trunk	Category not applicable	Category not applicable	Standard trunk postures: - Stand extension ($< 20^{0}$) - Stand Neutral - Stand-mild flexion ($20 <$ to $\leq 45^{0}$) - Stand Severe Flexion ($> 45^{0}$) - Stand-twisted/Bent ($> 20^{0}$ in either direction) - Lie on back or side - Sit-neutral - Sit-mild flexion - Sit-twisted/bent	Category not applicable	Category not applicable	- Almost neutral - Moderately flexed, twisted or side bent - Excessively twisted or side bent	Category not applicable

*Note: Posture scores are given as a percentage of total range of motion. The described categories are consistent for motions across the back and shoulder as well as the hand and wrist.

Table 3-10: Force cut points used to identify risk of musculoskeletal injury by method

Author(s):	**Colombini 1998, Occhipinti 1998, Grieco 1998**	**Moore and Garg 1995**	**Li and Buckle 1998**	**Genaidy et al. 1993**
Description:	An upper extremity posture is considered static when it is held for more than 4 seconds. Force factor: Mean force perceived / mean effort in percentage with respect to MVC - ≥ 0.5 / ≥ 5 - 1 / 10 - 1.5 / 15 - 2 / 20 - 2.5 / 25 - 3 / 30 - 3.5 / 35 - 4/ 40 - 4.5 / 45 - 5 / 50	Rating criterion/% max. strength/perceived effort: - Light /< 10%/ Barely noticeable or relaxed effort - Somewhat hard/10-29%/Noticeable or definite effort - Hard/30-49%/Obvious effort; unchanged facial expression - Very hard/50-79%/Substantial effort; changes facial expression - Near Maximal/ ≥ 80%/Uses shoulder or trunk to generate force	Maximum weight handled: - Light (5kg or less) - Moderate (6 to 10 kg.) - Heavy (11 to 20 kg.) - Very heavy (more then 20 kg) Maximum force exerted by one hand: - Low (e.g. less than 1 kg) - Medium (e.g. 1 to 4 kg.) - High (e.g. more than 4 kg)	% MVC static 0 - 1.6% 1.7 – 3.2% 3.3 – 6.4% 6.5 – 9.6% 9.7% +

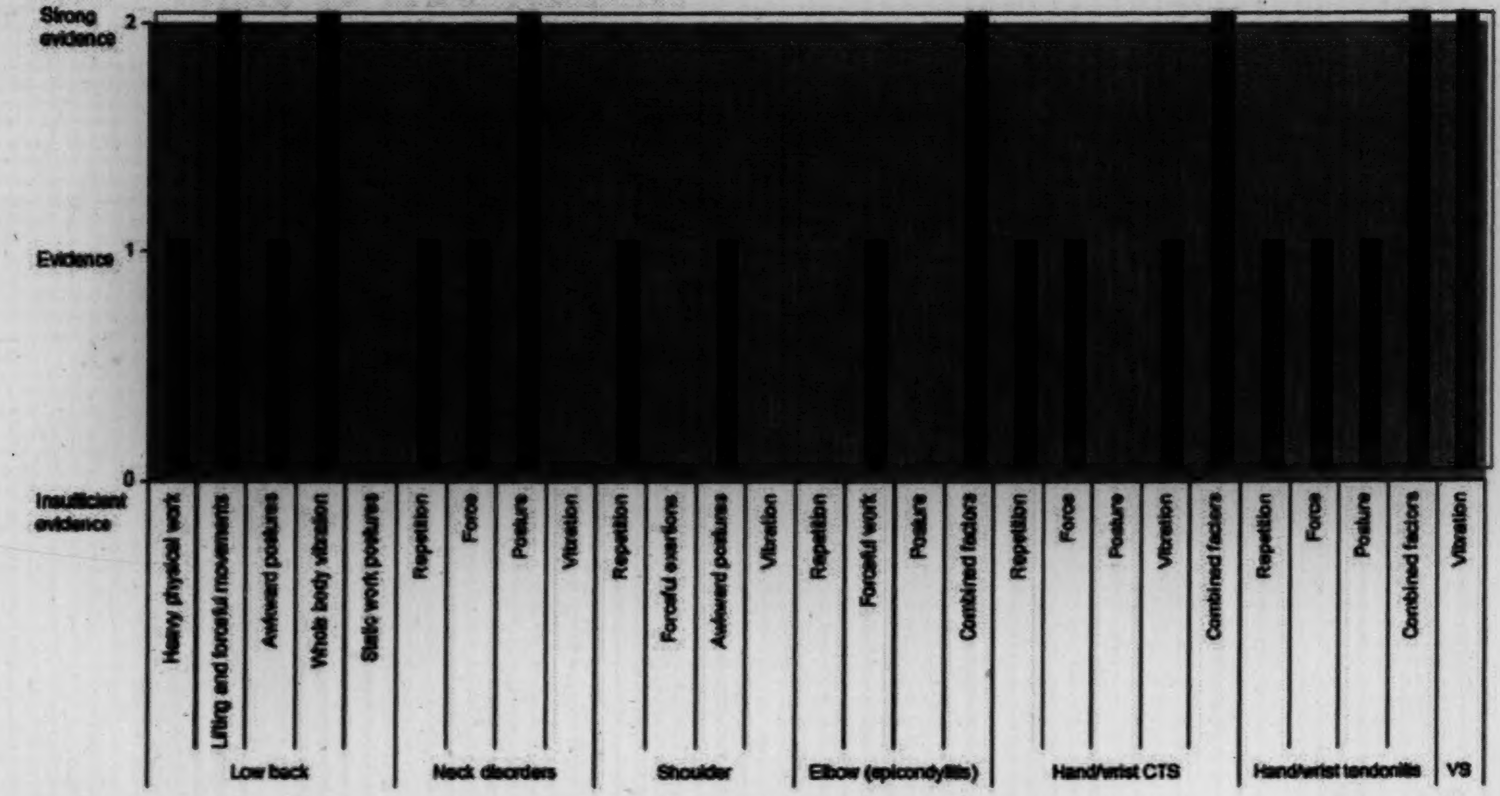
Table 3-11: Repetition/frequency cut points used to identify risk of musculoskeletal injury by method

Author(s):	**Colombini 1998, Occhipinti 1998, Grieco 1998**	**Moore and Garg 1995**	**James et al. 1997**	**Li and Buckle 1998**	**Genaidy et al. 1993**	**Latko et al. 1997.**
Description:	Calculation of the total number of recommended technical actions per shift is a product of the interaction of all variables considered.	Efforts per minute: - < 4 - 4-8 - 9-14 - 15-19 - ≥ 20	Duration constituting static posture not specified	For manual materials handling tasks only: Is the movement of the back B1: In frequent (around 3 times per minute or less) B2: Frequent (around 8 times per minute) B3: Very frequent? (around 12 times per minute or more) Is the arm movement repeated? D1: Infrequently (some intermittent arm movement) D2: Frequently? (regular arm movement with some pauses) D3: Very frequently?. (almost continuous arm movement) Is the task performed with similar repeated motion patterns? F1: 10 times per minute or less? F2: 11 to 20 times per minute? F3: More then 20 times per minute?	Repetitions per day: (0 – 0.5 Action limit) Fingers: (0 – 3656) Wrist: (0-1951) Elbow/Shoulder./Neck: (0-473) (0.6 – 1.0 Action limit) Fingers: (3657-7312) Wrist: (1952-3902) Elbow/Shoulder./Neck: (474-946) (1.1 – 2.0 Action limit) Fingers: (7,313-14-624) Wrist: (3903-7804) Elbow/Shoulder./Neck: (947-1893) (2.1 – 3.0 Action limit) Fingers: (14625 – 21936) Wrist: (7805-11706) Elbow/Shoulder./Neck: (1894-2838) (3.1 + Action limit) Fingers: (21937+) Wrist: (11707+) Elbow/Shoulder./Neck: (2839+)	Repetitions per cycle described in terms of duration and frequency of observed rest pauses and the speed of hand movements. Repetition or hand activity is characterized using a visual analog scale ranging form the lowest to the highest amount imaginable. The rating system consists of a 10 cm visual analog scale that ranges form 0 which corresponds to no hand activity to 10 the most possible hand activity. 0 - Hands idle most of the time; no regular exertions 2- Consistent conspicuous, long pauses; or very slow motions 4 - Slow steady motion/exertion; frequent brief pauses 6- Steady motion /exertion; infrequent pauses 8 - Rapid steady motion/exertion; no regular pauses 10 - Rapid steady motion/exertion; difficulty keeping up

Table 3-12: Additional factors, description and cut points used to identify risk of musculoskeletal injury by method

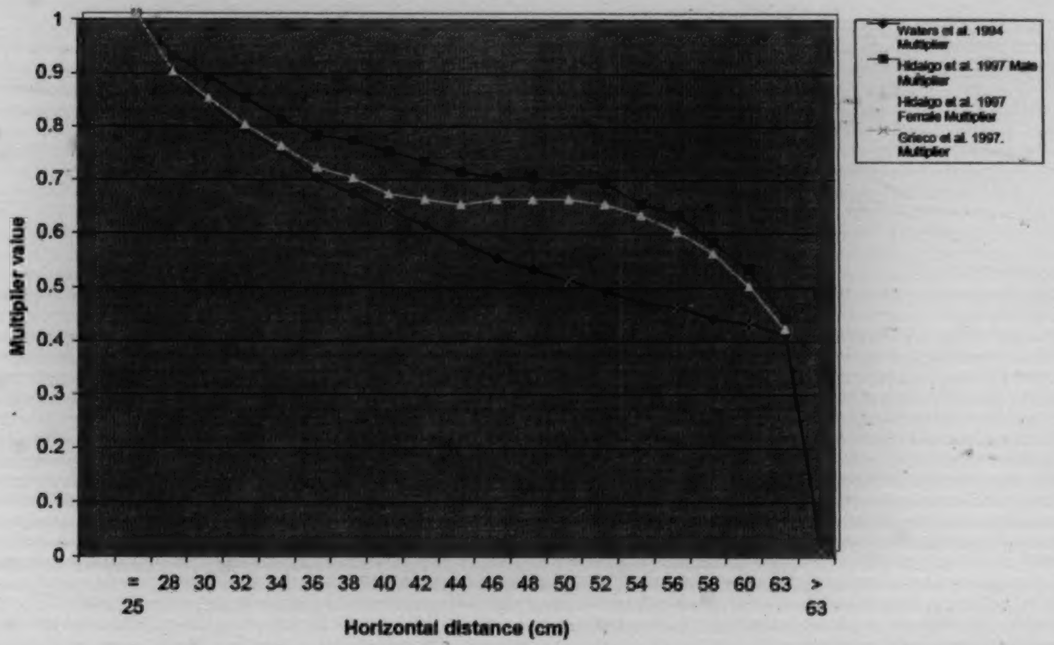
Author(s):	**Cololmbini 1998, Occhipinti 1998, Grieco 1998**	**Moore and Garg 1995**	**Keyserling 1986**	**Li and Buckle 1998**
Description:	Grip scores: - Wide grip (4-5 cm.) - Tight grip (1.5cm) - Fine finger movements - Pinch - Palmer grip - Hook Grip Risk due to additional factors (Vibration, velocity and acceleration, precision, localized compression, exposure to cold, use of gloves, coupling, wrenching movements, return shock) quantified by dichotomous classification and percentage of cycle present (e.g., 1/3, 2/3, 3/3). Risk due to inadequate recovery calculated by applying the appropriate multiplier to the number of hours observed without adequate recovery.	Speed of work: Rating criterion/MTM-1/Perceived speed - Very Slow/≤ 80%/Extremely relaxed pace - Slow/ 81-90% /"taking ones own time" - Fair/91-100%/"normal" speed of motion - Fast/101-115%/Rushed/ but able to keep up - Very fast/>115%/Rushed and barely able or unable to keep up Duration of exertion (percentage of cycle) - < 10 - 10-29 - 30-49 - 50-79 - ≥ 80 Duration per day - ≤ 1 - 1-2 - 2-4 - 4-8 - ≥ 8	Subjective discomfort: - non existent or very slight - slight - moderate - severe	Duration of time spent performing a task: - Less than 2 hours - 2 to 4 hours - More than 4 hours Vibration exposure during work: - Low (or no) - Medium - High Visual demand: - Low (There is almost no need to view fine details) - High (There is a need to view some fine details) Difficulty keeping up with this work? (Work pace) - Never - Sometimes - Often How stressful do you find this work? (work stress) - Not at all - Low - Medium - High

Figure 3-1: 1997 NIOSH review of epidemiologic evidence.



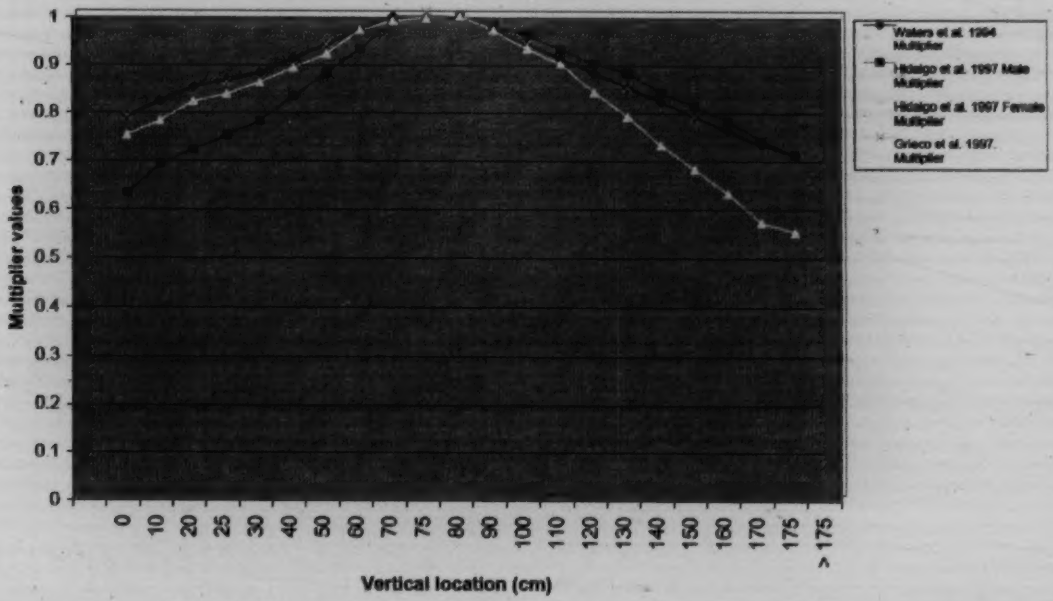
Epidemiological evidence of work relatedness by physical factor as presented by NIOSH 1997 (4).

Figure 3-2: Horizontal multiplier comparison



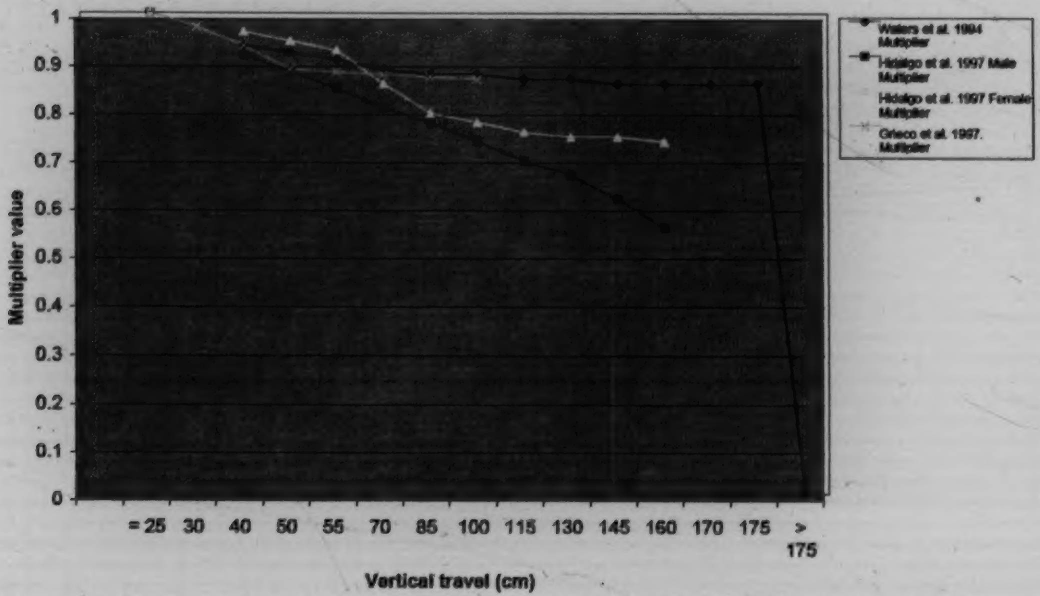
Comparison of horizontal multiplier values between lifting methods described by Waters et al. 1993, Hidalgo et al. 1997, and Grieco et al. 1997. Multiplier values of the methods compared were interpolated to enable comparison. Multiplier values presented for Hidalgo et al. 1997 were adapted from graphical form (22-24).

Figure 3-3: Vertical location multiplier comparaison



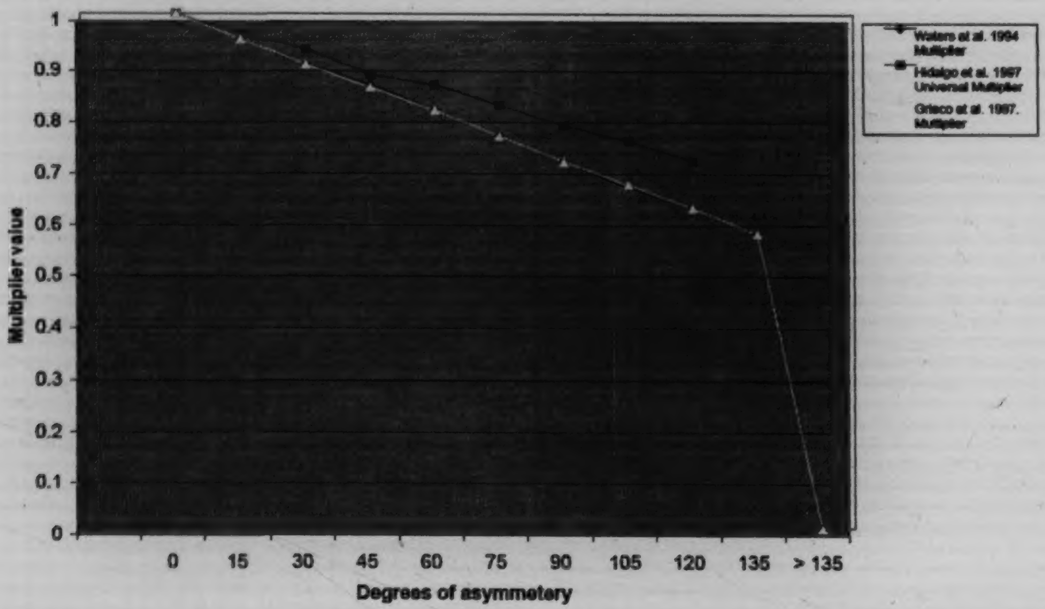
Comparison of vertical location multiplier values between lifting methods described by Waters et al. 1993, Hidalgo et al. 1997, and Grieco et al. 1997. Multiplier values of the methods compared were interpolated to enable comparison. Multiplier values presented for Hidalgo et al. 1997 were adapted from graphical form (22-24).

Figure 3-4: Vertical travel multiplier comparison



Comparison of vertical travel multiplier values between lifting methods described by Waters et al. 1993, Hidalgo et al. 1997, and Grieco et al. 1997. Multiplier values of the methods compared were interpolated to enable comparison. Multiplier values presented for Hidalgo et al. 1997 were adapted from graphical form (22-24).

Figure 3-5: Asymmetry multiplier comparison



Comparison of asymmetry multiplier values between lifting methods described by Waters et al. 1993, Hidalgo et al. 1997, and Grieco et al. 1997. Multiplier values of the methods compared were interpolated to enable comparison. Multiplier values presented for Hidalgo et al. 1997 were adapted from graphical form (22-24).

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Chapter 4 – Six years of injuries and accidents in the sawmill industry of Alberta

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4.1 Introduction

In the sawmill industry of Canada an average of 69,006 person years were worked in the period between 1997 and 2001 (Statistics Canada, 2003a,b). In the same time period the sawmill industry contributed an average of 6.5 billion dollars to the Canadian gross domestic product (Statistics Canada, 2003c). The sawmill industry of Alberta, Canada, generated 0.5% of the provincial gross domestic product in 2001 and employed an average of 6,589 (S.D 397) full time equivalent workers annually (Reurink, 2003).

The manufacturing and processing sector of Alberta, Canada, maintained the highest lost time claim rate of all industrial sectors during the five year period from 1997 to 2001(Alberta Human Resources and Employment 1998, 1999, 2000, 2001, 2002). The forest products manufacturing sub-sector (within the manufacturing and processing sector) has exceeded the lost time claim rate of the manufacturing and processing sector by an average of 14.4% in the five years previous to 2002 and has had a lost time claim rate an average of 42% higher than the provincial average (Alberta Human Resources and Employment 1998, 1999, 2000, 2001, 2002). In the forest products manufacturing sub-sector the sawmill industry falls second among the forest products manufacturing industries in terms of lost time claim rate. Based on a five year average lost time claim rate, the sawmill industry specifically, had a lost time claim rate 55% higher than the provincial rate, 2% higher than the manufacturing and processing sector average and 11% lower than the forest products manufacturing group average. Injuries and illnesses in the sawmill industry resulted in 3,779 accepted Workers Compensation Board (WCB) claims from 1997 to 2002.

A descriptive analysis was performed on claims occurring within the sawmill industry of Alberta for the purpose of assisting employers to develop and improve health and safety programs addressing prevention and rehabilitation of workplace injuries. The study was performed by analyzing a comprehensive Workers Compensation Board (WCB) of Alberta dataset of claims occurrence in the forest products manufacturing industries of Alberta. Description of claim trends by accessing the WCB of Alberta's database is currently the most accurate method of describing occupational injury/accident trends in Canada. Census data are available in Canada however; census data are not collected in concurrent years and is primarily based on the subjective report of the general population. In addition to the subjectivity of the data the lack of continuous data collection makes it difficult to control for the biasing effects of industry change due to legislation, market, technology etc. as is somewhat possible when analyzing a sample collected in concurrent years. Data collected by federal agencies describing hospital admissions are also collected; however the scope of this data is limited when considering work-place injury/accident trends as many injuries occurring in the work-place do not result in a hospital visit. No detailed information describing workplace injuries/illnesses within the sawmill industry specifically is currently available from either provincial or federal sources. Documents available from federal and provincial sources describe trends in industry subgroups only, in limited detail, and do not describe the characteristics of the individual industries comprising those groups. Further, documents available from provincial and federal sources describe lost time claims only and make no reference to those claims which result in medical aid. The objectives of this study are: identify claims trends in terms of nature of injury, type of accident or exposure, source of injury, and body part injured; determine the effect of work experience and worker age on the above mentioned classifications; assess the impact of observed claims trends in terms of cost and duration of claim; and compare incidence rates of nonfatal injuries resulting in Workers Compensation Board claims in Alberta, Canada to those reported by the Bureau of Labor Statistics in the United States.

No peer reviewed literature describing the characteristics of injured/ill workers generally or injuries/illnesses specifically was located for the wood processing industries of Canada. With respect to epidemiologic studies examining the forestry industry generally and the sawmill industry specifically only five studies could be located. Three studies describe only the logging and silviculture industry of New Zealand and not the wood products manufacturing industry sectors (Bentley et al. 2002, Marshal et al. 1994, Macfarlane 1980). Layne and Landen (1997) describe injury characteristics in the forestry industry based on hospital emergency records but provide limited detail with regard to specific industries. Only the study by Jinadu (1990) describing the 12 month history of workplace accidents in the wood products manufacturing industries of Nigeria presents injury characteristics similar to those described here.

4.2 Methods

A comprehensive dataset describing claims occurring form 1997 to 2002 was obtained from the Workers Compensation Board (WCB) of Alberta, Canada, for the purpose of performing a descriptive study addressing claim trends in the forest products manufacturing industries of Alberta. This paper is limited to those descriptive analyses performed on the sawmill industry. Within the database coded claim numbers were generated for all claims to protect claimants from identification. Coded account numbers were also generated to protect individual companies operating within the industry from identification. Recurrent incidences of the same injury within individuals were not considered separately as this circumstance resulted in the claim being reactivated under the original claim number. Multiple claims within the same individual at different time periods were considered separately and included in the description of claim trends. Data allowing the determination of claims cost, duration of claim and nature of claim (lost time claim versus medical aid only) were controlled by limiting data considered to March 31 of the following year to introduce a measure of comparability between the years considered. For this reason only those claims occurring from 1997 to 2000 are considered in mean, median and standard deviation reported with respect to duration, cost, and LTC/MA status. Duration of claim is based on date of accident. Only the time loss, claims cost and LTC/MA status data fields are time sensitive and thus only the trends described with respect to these data fields have been limited to the time period from 1997-2000. The database supplied by the WCB contained the most detailed coding of the fields reported possible. The coding system used by the WCB Alberta is consistent with those used across Compensation Boards in Canada and the Bureau of Labor Statistics (BLS) in the United States. A description of specific classifications within the data fields considered (with the exception of occupation classification) is available from the Canadian Standards Association in document Z795-96 (2001). The data field codes (individual classifications) were individually considered and grouped by the authors into the categories reported. This was done to facilitate future studies of specific classification incidence within the characteristic groupings (i.e. low back injuries) and provide increased detail to the reader. Percentages of individual classifications pertaining only to Alberta figures reported within the categories are based on the valid percentages (do not consider missing data). A total of 3,779 WCB claims occurred in the sawmill industry of Alberta from January 1, 1997 to Dec 25, 2002. The comprehensive WCB database considered both claims resulting in medical aid only (MA) and claims resulting in days off or lost time claims (LTC). LTC claims were defined as those claims which incur compensation and/or pension costs form the date of accident to March 31 of the following year (hence 15 months of costs development). A MA claim is defined as a claim that incurs only medical aid costs. Both claim types are considered in the claim trends described. Age of the injured worker was reported at the time of injury and experience by days employed before injury. Canadian employment and gross domestic product figures (provincial and national) are estimated as a possible disparity between the industry classification system used by the WCB of Alberta and that used by provincial and federal agencies (North American Industrial Classification System) exists.

To enable comparison between incidence rates observed in Alberta and those reported by the BLS the coding structure adopted by the BLS was used to re-categorize the characteristics of Alberta Claims. Reported Alberta incidence rates were calculated by dividing observed occurrence by person years worked. Total person years worked in the sawmill industry was determined by dividing the total insurable earnings in the sawmill industry by the average industry wage according to WCB figures. Incidence rates of the specific characteristic groups were averaged across the five years from 1997-2001 and compared. Disparity may exist between the industrial classification systems used by the BLS and the WCB of Alberta. In this study industry 2421 (Sawmills and

Planing Mills General) as identified by the Standard Industry Classification used by the BLS and industry 25100 (Sawmills, Planing Mills, Specialized Remanufacturing, Restoration of Railway Ties, Manufacture of Wooden Shakes) as identified by Alberta Human Resources and Employment were compared. Both overall incidence of non fatal injuries and illnesses, and specific injury/illness characteristics (e.g. nature of injury) were compared according to the groupings specified by the BLS. Overall BLS incidence statistics consider cases without lost work days, cases with restricted work activities only, and cases with lost work days. Reported BLS statistics examining claims characteristics (i.e. sprains and strains or upper extremity injuries) consider only cases resulting in lost work days. Incidence rates reported for the Alberta Sawmill group include all successful claims including those defined as lost time claims and those defined as medical aid only. It is not possible to separate lost time claims into those resulting in days lost and those resulting in restricted activities only in the case of the Alberta dataset. BLS data report incidence rates per 10,000 person years worked, as an annual average of 6,589 person years were worked in Alberta during the period examined (1997-2002). Alberta figures were adjusted to enable comparison to BLS figures. With respect to the comparisons of specific injury characteristic groups, WCB data set figures were adjusted by a factor of 1.518 to arrive at incidence rates per 10,000 person years worked. With regard to comparisons of incidence rates of the characteristics of injuries/illnesses, BLS incidence rates describe lost work day cases resulting in days away from work only (not including those which required restricted work activity only). Comparisons to three Alberta claims groups are described in tables to follow (MA only, LTC only, total claims). BLS incidence data reported is based on non-fatal occupational injuries and are defined as involving one or more of the following: loss of consciousness, restriction of work or motion, transfer to another job or medical treatment (other than first aid).

4.3 Results

4.3.1 Number of workers employed and total claims incidence

During the five year period described an average of 6,589 (S.D. 397) person years were worked in the sawmill industry of Alberta. Comparison of incidence rates of nonfatal occupational injuries and illnesses per 100 person years worked between the WCB Alberta dataset and that presented by the BLS is presented in table 4-1.

4.3.2 Characteristics of the injured workers

Males accounted for 88% of accepted claims and females for 10.2% of accepted claims from 1997 to 2002. The 25-34 year old age group experienced the highest proportion of claims at 32.8% followed by the 35-44 year age group at 24.1% and the 20-24 year age group at 18.5% of the total. The mean age of the injured worker was 32.5 years with a standard deviation of 11.02 years. The number of days worked previous to experiencing the injury/accident that resulted in an accepted claim was highest in the 1- 6 month experience group at 23.8 % of the total claims followed by the 2-5 years experience group at 17.6% and the 5- 10 years experience group at 13.0% of claims. Within the database examined only 46.3% of claims contained information describing work experience before the injury/accident, conclusions drawn from the interpretation of claim trends may therefore be affected. Claims experience by occupation group as defined by the 1971 National Occupation Classification of the ten most frequently occurring occupation titles and their relative percentage are presented in table 4-2. Within the occupation classification 63.5% of claims provided information on job title. Conclusions drawn from observed trends by occupation classification may therefore also be affected.

4.3.3 Nature of injury

4.3.3.1 Comparison of Alberta and BLS nature of injury statistics

The specific nature of injury classifications reported here were grouped first according to the scheme used by the BLS to enable comparison of incidence rates per 10,000 person years worked and second into groups selected by the authors. Table 4-3 presents a comparison of the incidence rates, between the BLS and Alberta, using the nature of injury category scheme adopted by the BLS.

4.3.3.2 Detailed description of the nature of injuries

Musculoskeletal disorders accounted for the highest percentage of accepted claims in the sawmill industry from 1997-2002 at 46.7 % of claims, followed by the wound (cut/amputation/other) category at 31.9 % and the trauma group at 15.6 % of claims. Nature of injury classification was present for 96.2% of claims. Within those injuries classified as musculoskeletal in nature 76.6% of injuries were classified generally as sprain, strains, or tears. The second and third most commonly occurring nature of injury within the musculoskeletal injury category were tendonitis at 5.9% and soreness/pain hurt except back at 5.9 percent respectively. Of those injuries classified as wound (cut/amputation/other) 41.9% percent of claims were classified as bruise/contusion followed by cut laceration at 32.0% and foreign body at 7.0%. To summarize the third highest occurring nature of injury category, traumatic injuries, fractures were the most frequently occurring classification at 69.5% of claims followed by crushing injuries at 20.8% and dislocation at 5.3 %.

4.3.4 Type of event or exposure

4.3.4.1 Comparison of Alberta and BLS type of exposure statistics

Table 4-4 presents a comparison of the incidence rates, between the BLS and Alberta, using the type of exposure category scheme adopted by the BLS.

4.3.4.2 Detailed description of the type of exposure

Type of event or exposure classification was present for 84.2% of claims. Within the type of event or exposure field struck by/contact with was the most frequently occurring type of event or exposure category accounting for 30.4% of claims. Bodily reaction/exertion was the second most frequently occurring category of event/exposure with 27.9 % of claims. The third highest occurring type of event or exposure category was the caught in category which accounted for 16.4% of claims. Within the struck by/contact with category the general struck by object classification accounted for 25.6% of claims followed by struck by falling object at 17.9% and struck against stationary object at 9.1% of claims. Within the bodily reaction/exertion category the highest relative percentage of claims were classified as overexertion while lifting at 25.4%

followed by overexertion general at 21.3% and overexertion while pushing/pulling object at 16.5% of claims. Finally within the caught in category of the type of event or exposure field the highest relative percentage of claims occurred in the general caught in equipment/objects category at 53.1% of claims followed by the caught in running equipment classification at 31% and pinched by rolling/sliding objects at 15.9% of claims.

4.3.5 Part of body injured

4.3.5.1 Comparison between Alberta and BLS body part injured statistics

Table 4-5 presents a comparison of the incidence rates, between the BLS and Alberta, using the body part category scheme adopted by the BLS.

4.3.5.2 Detailed description of the part of body injured

Upper extremity injuries accounted for 45.5% of claims in the sawmill industry of Alberta, Canada from 1997 to 2002. The lower extremity accounted for the second highest percentage of claims at 17.5% of claims and the spine/trunk accounted for the third highest relative percentage of claims at 17.3% of claims. Part of body injured classification was present for 99.3% of claims. Within the upper extremity category the fingers-except thumb classification accounted for the highest percentage of claims with 27.0% followed by the hand except fingers at 16.0% and the shoulder including clavicle, scapula at 14.3% of claims. Ankle injuries accounted for the highest percentage of lower extremity injuries at 34.7% followed by the knee at 25.5% and the foot-except toes general category at 15.0% of claims. Within the spine/trunk category claims classified as lower back, unspecified location code accounted for the highest percentage of claims at 43.1% followed by the general back including spine/spinal cord classification at 37.3% and the lumbar region classification at 6.9% of claims.

4.3.6 Source of injury

4.3.6.1 Comparison between Alberta and BLS source of injury statistics

Table 4-6 presents a comparison of the incidence rates, between the BLS and Alberta, using the source of injury category scheme used by the BLS.

4.3.6.2 Detailed description of the source of injury

Source of injury classification was present for 75.5% of claims. Within the source of injury field, injuries caused by parts and machinery accounted for the highest percentage of claims at 34.4% of claims. Bodily condition or motion accounted for the second highest percentage of claims at 16.3% of claims and tools (powered/non) accounted for the third highest percentage of claims at 10.2% of claims. Within the parts and machinery category the general wood/lumber classification accounted for the highest percentage of claims at 38.3% followed by the general dimensional lumbar category at 10.6% and the lumbar with dimension greater than 4 inches at 6.2% of claims. Within the bodily condition or motion category 100% of the claims related to the bodily condition-injured/ill worker classification. The cart/dolly/hand-truck classification accounted for the highest percentage of claims in the tools (powered/non) category at 12.1% followed by the saw power not determined classification at 9.0% and the crowbar classification at 7.9% of claims.

4.3.7 Cost and duration of claims

The data fields of claim classification (lost time claim vs. medical aid only), total time lost due to injury/accident, and total cost of injury were normalized to include values accumulated to March 31 of the following year only. The figures reported in this section reflect this time period in an effort to control for the confounding effect of different cost/time/etc. accumulation due to duration of the claim at the time of database extraction. Only those claims occurring in the four year period form 1997 to 2000 were considered in the following section to ensure all claims had adequate time to accumulate claims costs etc. Of the claims accepted by the WCB of Alberta, Canada in the sawmill industry from 1997 to December 31, 2000 53.5% incurred compensation and/or pension costs and were therefore considered lost time claims. 46.5% of claims resulted in medical aid costs only and required no time away from work. The median days lost from work due to injury/accident in the sawmill industry from 1997 – 2000 was 1 with a standard deviation of 33 days. An average of 8,924 days were lost annually during the period examined due to injury/accident resulting in a WCB claim. The mean, median, and standard deviation of claim cost was $2,348, $369, and $8,998 respectively. An average annual cost of $ 1,623,663 was incurred due to claims in the sawmill industry.

4.4 Discussion

4.4.1 Worker characteristics: Age and experience

No census information was available indicating the characteristics of the total sawmill work force. For this reason calculation of relative risk given specific characteristics of the population could not be derived. The mean cost and duration of claim was observed to increase as age increased. The mean cost of claim in the 55-64 year age group was 1.96 times greater than that in the 15-19 year age group. Mean duration of claim in the 55-64 yr. age group was 1.77 times that of the 15-19 yr age group. This trend is to be expected due to the lower injury thresholds and the body's decreased ability to heal following accident or injury with age. Only a moderate correlation was found between cost and duration of claim (r = .55). Analysis of percentage of claims by nature of injury by age group revealed that wound injuries were 1.87 times more frequent in the 15-19 year age group as the 55-64 year age group. The highest proportion of musculoskeletal injuries was observed in the 25-34 and 35-44 year age groups with the proportion of claims classified as MSI in nature falling on either side of these age categories. Traumatic injuries consistently accounted for a five year average of 16% of claims. The above described trends are illustrated for the reader in figure 4-1. Trends illustrated in figure 4-1 are based on the linear regression model normalized to the highest value and excluding groups smaller than 30 in the cases of cost and duration of claims. Nature of injury trends illustrate the percentage of claims attributable to the described group. Further analysis of the days employed before accident (work experience) category revealed similar trends as the age of worker analyses. Description of the part of body injured by experience group revealed a decreasing proportion of upper extremity injuries with experience (<1yr experience 49.67% of claims compared to >1yr experience 36.1% of claims) and an increasing proportion of spine/trunk injuries (<6mos. experience 16% of claims compared to 29% of claims in those with >15 years of experience). Source of injury analysis revealed a progressive decline in injuries/accident resulting from parts and machinery (from 38% of claims in the <1 month experience group to an average of 20% of claims in those with >10 years of experience). The proportion of claims resulting from bodily motion were observed to increase with increasing experience as well (9% in those with <1 month of experience to 23% in the 10-15 year experience group). The trends described above in reference to work experience are depicted in 2. The reader is reminded that the worker experience data field contained information in only 46.3% or 1,750 claims therefore conclusions drawn from these observed trends may be affected. Trends illustrated in figure 4-2 are based on the linear regression model normalized to the highest value and excluding groups smaller than 30 in the cases of cost and duration of claims. Nature of injury, source of injury and body part injured trends illustrate the percentage of claims attributable to the described group. The distribution of age within occupation groups has not been accounted for but is taken to be an important limitation of this study. Physical exposure given required job demands (specific to occupation) will vary significantly among age groups given the tendency towards supervisory work at higher ages. Thus observed differences in nature of injury groupings among age and experience groups may be largely due to the variability in occupations (tasks) those groups are performing.

4.4.2 Cost and duration of claims: by injury/accident category

Within the nature of injury groupings the categories of traumatic injuries and burns accounted for the highest mean cost and mean days lost. However in terms of percentage of total cost and total days lost the overall incidence of claims falling within the characteristic group (i.e. musculoskeletal injuries) is arguably the best indicator of the impact on industry. In terms of percentage of total cost, musculoskeletal injuries and traumatic injures accounted for the highest percentage at 32% respectively followed by wound injuries at 27% of claims classified. Total incidence of the characteristic group continues to be the most important indicator of percentage of total cost and total days lost when analyzing the type of accident or exposure field. The type of exposure categories with highest overall incidence account for the highest percentage of costs and days lost. Again the categories associated with traumatic type injuries (i.e. caught in vs. bodily reaction/exertion) are associated with higher mean claim costs and days lost, and higher lost time claim to medical aid ratios (LTC to MA). Of the three most commonly injured body parts mean cost per claim was highest in lower extremity injuries followed by spine/trunk injuries and finally by upper extremity injuries. Mean days lost due to injury however was highest in the lower extremity group followed by the upper extremity and lastly the spine/trunk. Percentage of total cost and days lost was again reflective of overall characteristic group incidence with the overwhelming majority of costs and days lost due to upper extremity injuries followed by the lower extremity and lastly the spine/trunk. The LTC to MA ratio was highest in the lower extremity group followed by the spine/trunk and finally the upper extremity. Analysis of the source of injury/accident field again revealed the source of injury more likely to result in traumatic type injuries (injuries/illnesses due to machinery) were associated with higher mean claims costs and days lost (also reflected in higher LTC to MA ratios) while overall percentage of claims costs and days lost were largely influenced by overall incidence.

4.4.3 Comparison of WCB and BLS incidence rates

Significant differences exist between the incidence rates reported by the BLS and those observed in the sawmill industry of Alberta from 1997 to 2001. Possible explanations for this disparity include fundamental differences in the industry groups, differences in the reporting structure and data collection methodology, differences in the sawmilling industrial processes of the two countries, and environmental factors. Differences in the method of determining person years worked between Alberta figures and BLS figures may contribute substantially to differences in incidence rates. Person years worked in Alberta were determined by total insurable earnings divided by average industrial wage and averaged over five years and adjusted for comparison to BLS incidence rates, BLS data is based on total hours worked by employees during the calendar year. The method used in Alberta may underestimate hours worked by low hourly wage earners and thus over express injury/illness trends in this population. Further, comparison of the incidence rates specific to the characteristics of successful WCB claims (e.g. sprains and strains) versus BLS incidence rates is confounded by the inability to separate Alberta lost time claims into those with lost time days and those with days of restricted work activity only. Reported BLS incidence rates examining claims characteristics (i.e. sprains and strains or upper extremity injuries) consider only cases resulting in lost work days. Despite the above limitations the comparisons made serve as an important indication of the differences in incidence rates in the two different industrial environments, given a complete population of claims collected in Alberta was compared to a sample collected from 178,000 employer reports, based on a five year averages, using the same coding structure.

4.5 Conclusion

It has been demonstrated from the above analyses that as the age of the worker increases mean cost and duration of claim figures also increase. Interestingly as the days worked increased so do the likelihood of musculoskeletal injury increase, the important role of physical exposure given occupational demands remains largely unevaluated however. Comparison of the incidence rates of specific injury/illness characteristic categories indicates that incidence rates reported by the BLS based on the survey of occupational injuries and illness are not representative of incidence rates observed in Alberta, Canada. Within the nature of injury field category of musculoskeletal injury, claims classified generally as sprain/strain/tear are more numerous than the total claims falling under the wound or traumatic injuries categories. The high proportion of claims classified in this general classification suggests that more detail is required in the classification systems used by Workers Compensation Boards across Canada and that used by the Bureau of Labor Statistics in the United States. The predominance of musculoskeletal injuries within this industry suggests that intervention strategies directed at the prevention and treatment of sprain/strain/tears may have the greatest impact on overall costs and days lost. With regard to the part of body injured, upper extremity injuries clearly have the greatest impact on overall costs and days lost in the sawmill industry followed by the lower extremity and the spine/trunk. Again interventions focused on body regions in this order, taking into consideration the type of accident/exposure and the source of the injury, have the greatest potential to reduce injuries and illnesses in the sawmill industry.

4.6 Acknowledgement

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Table 4-1: Comparison of nonfatal occupational injuries and illnesses incidence rates in the sawmill industry of Canada and the USA.

		Incidence rate per 100 person years worked	% diff Alberta vs. BLS
Alberta	LTC & MA	9.9	-22%
	LTC	5.3	-21%
	MA	4.7	-21%
BLS	LWC & WLW	12.1	
	LWC	6.4	
	WLW	5.7	

Comparison of nonfatal occupational injuries and illnesses incidence rates in the sawmill industry of Canada and the USA. Lost time claims (LTC) and Medical Aid claims (MA) compared to Lost Workday Cases (LWC), including cases with days away from work and cases with restricted work activity only, and Without Lost Workday cases (WLW). Incidence rates are based on the 5 year average 1997-2001 (Bureau of Labor Statistics 2003a)

Table 4-2: Top ten occupation classifications by claims incidence in the sawmill industry of Alberta, Canada from 1997 to 2002.

Rank	**Occupation description**	**Percent of total classified**
1	General laborers	11.7
2	Laborers wood processing except pulp	8.7
3	Industrial/farm/construction on machinery	5.7
4	Laborers materials handling	5.0
5	General equipment operators	3.7
6	Sawmill sawyers/related fields	2.2
7	Wood sawyers/related except sawmill	1.7
8	Inspectors/testers/graders/samplers, wood processing except pulp	1.6
9	Laborers forestry/logging	1.6
10	Wood processors except pulp	1.5

Table 4-3: Nature of injury category incidence comparisons

	Sprains and strains	Fractures	Cuts and punctures	Bruises	Heat burns	Chemical burns	Amputations
Alberta LTC and MA	343.7	104.1	112.6	126.6	2.7	0.9	19.7
Alberta LTC	191.9	66.8	51.0	69.5	1.8	0.6	17.0
Alberta MA	151.8	37.3	61.6	57.1	0.9	0.3	2.7
BLS LWC	144.3	47.7	50.2	54.1	3.1	0	8.2
% diff LTC and MA	138%	118%	124%	134%	-13%	No data	140%
% diff LTC	33%	40%	2%	28%	-42%	No data	107%
% diff MA	5%	-22%	23%	6%	-71%	No data	-67%

Carpal tunnel syndrome	Tendonitis	Multiple traumatic injuries and disorders			Back pain and pain except back		All other natures
		Total	With fractures, burns and other injuries	With sprains and bruises	Total	Back pain, hurt back only	
12.8	26.1	7.0	0	0.9	44.6	18.2	191.0
6.1	13.7	3.3	0	0.6	15.2	6.7	86.5
6.7	12.5	3.6	0	0.3	29.4	11.5	104.4
4.7	4.5	13.2	4.5	4.7	19.0	7.7	66.1
172%	480%	-47%	0%	-81%	135%	136%	189%
30%	204%	-75%	0%	-87%	-20%	-13%	31%
43%	177%	-72%	0%	-94%	55%	49%	58%

Alberta Human Resources and Employment vs. Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics 2003b).

Table 4-4: Type of exposure category comparisons

	Contact with objects				Fall to lower level	Fall on same level	Slips or trips without fall	Overexertion	
	Total	Struck by object	Struck against object	Caught in or compressed or crushed				Total	In lifting
Alberta LTC&MA	413.5	174.3	76.8	135.1	34.3	49.8	19.4	166.7	61.9
Alberta LTC	242.0	101.4	44.0	83.8	21.9	29.4	14.0	93.8	34.9
Alberta MA	171.5	72.9	32.8	51.3	12.4	20.3	5.5	72.9	27.0
BLS LWC	194.2	98.2	31.3	53.8	16.8	32.1	8.5	99.3	44.0
% diff LTC&MA	113%	77%	145%	151%	104%	55%	128%	68%	41%
% diff LTC	25%	3%	41%	56%	30%	-8%	65%	-6%	-21%
% diff MA	-12%	-26%	5%	-5%	-26%	-37%	-36%	-27%	-39%

Repetitive motion	Exposure to harmful substance or environment	Transportation accidents	Fires and explosions	Assaults and violent acts			All other events
				Total	By person	All other assaults	
35.4	27.3	18.2	0.6	1.2	1.2	0	225.6
18.2	11.5	7.6	0.3	0.6	0.6	0	84.1
17.0	15.8	10.6	0.3	0.6	0.6	0	141.5
8.4	6.4	6.2	No data	No data	No data	No data	40.2
321%	326%	194%	No data	No data	No data	No data	461%
117%	80%	23%	No data	No data	No data	No data	109%
102%	147%	71%	No data	No data	No data	No data	252%

Alberta Human Resources and Employment vs. Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics 2003b)

Table 4-5: Part of body category comparisons

	Head			Trunk			Upper extremities			
	Total	Eyes	Neck	Total	Back	Shoulder	Total	Finger	Hand	Wrist
Alberta LTC and MA	87.1	37.4	24.0	287.8	167.6	62.8	377.1	163.0	72.3	54.3
Alberta LTC	37.3	17.9	11.8	155.7	92.0	29.8	193.1	84.4	34.9	31.9
Alberta MA	49.8	19.4	12.1	132.1	75.6	33.1	184.0	78.6	37.3	22.5
BLS LWC	25.1	13.4	5.8	137.2	83.2	20.6	123.1	59.5	18.4	18.8
% diff LTC and MA	247%	179%	314%	110%	101%	205%	206%	174%	293%	189%
% diff LTC	49%	34%	103%	13%	11%	45%	57%	42%	90%	70%
% diff MA	98%	45%	109%	-4%	-9%	61%	49%	32%	103%	20%

Lower extremities			Body systems	Multiple body parts	All other body parts
total	knee	foot			
177.0	45.8	38.9	4.9	26.7	4.9
107.8	25.2	23.4	1.5	14.3	0.3
69.2	20.6	15.5	3.4	12.4	4.6
98.3	22.2	26.2	2.4	20.4	4.8
80%	106%	48%	104%	31%	1%
10%	14%	-11%	-38%	-30%	-94%
-30%	-7%	-41%	38%	-39%	-4%

Alberta Human Resources and Employment vs. Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics 2003b)

Table 4-6: Source of injury category comparisons

	Chemicals or chemical products	Containers	Furniture and fixtures	Machinery	Parts and materials	Worker motion or position	Floor, walkways or ground surfaces	Hand tools	Vehicles	Health care patient	All other sources
Alberta LTC&MA	3.9	27.3	2.1	91.4	261.4	117.5	53.4	43.4	28.8	0	362.5
Alberta LTC	2.1	15.5	0	61.3	153.0	67.4	35.3	22.8	15.5	0	150.6
Alberta MA	1.8	11.8	2.1	30.1	108.4	50.1	18.2	20.6	13.4	0	211.9
BLS LWC	No data	12.4	2.7	54.1	158.3	44.9	42.2	20.8	23.9	No data	53.6
% diff LTC&MA	No data	120%	-22%	69%	65%	162%	27%	109%	21%	No data	576%
% diff LTC	No data	25%	0%	13%	-3%	50%	-16%	10%	-35%	No data	181%
% diff MA	No data	-5%	-22%	-44%	-32%	12%	-57%	-1%	-44%	No data	295%

Alberta Human Resources and Employment vs. Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics 2003b).

Figure 4-1: Claim trends by age group in the sawmill industry of Alberta, Canada from 1997-2000

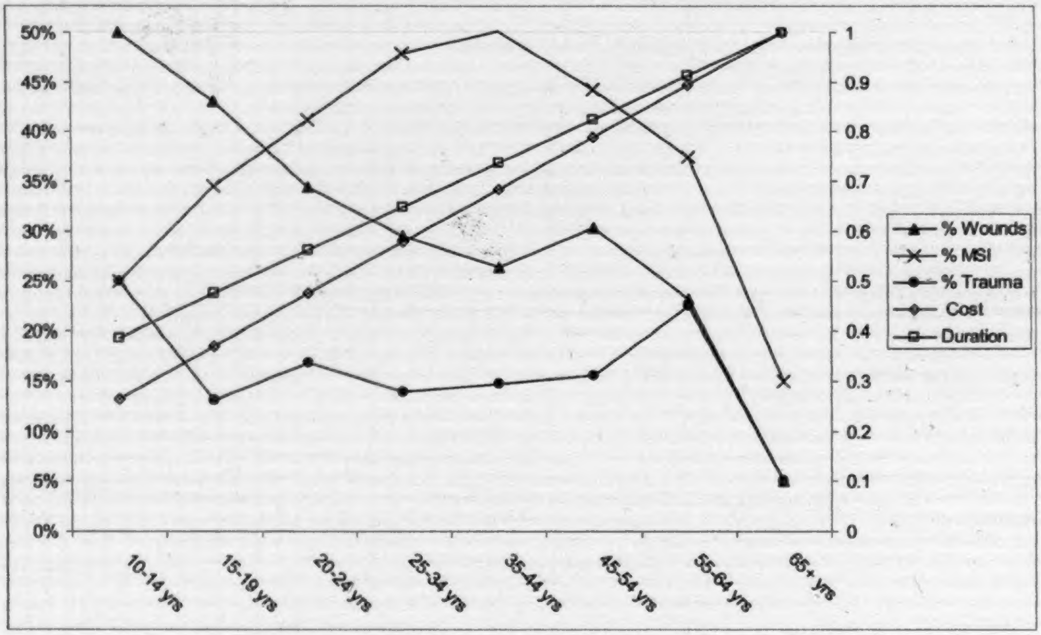
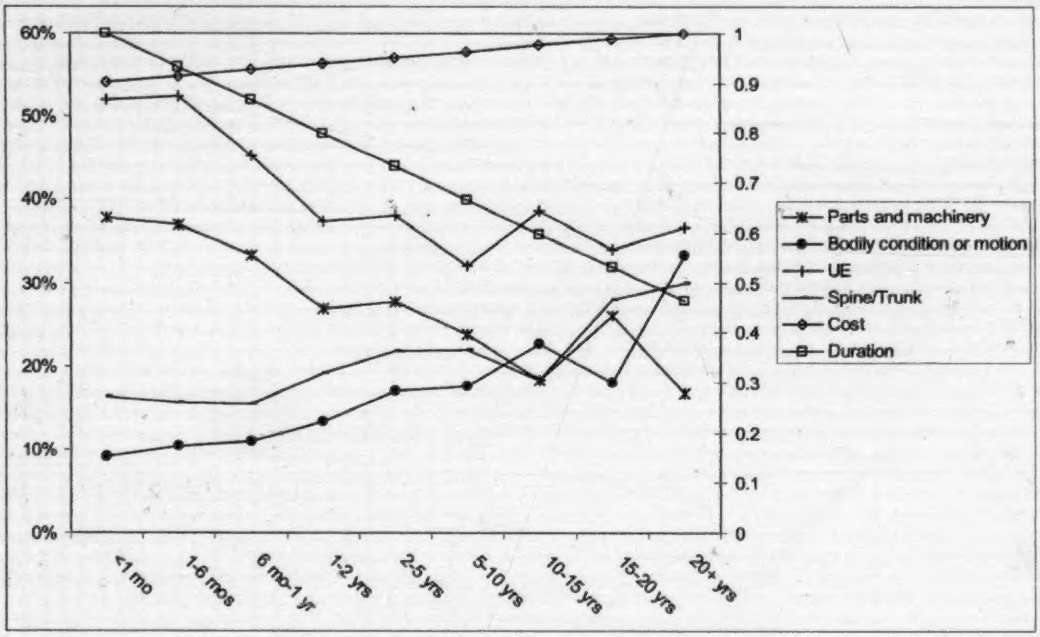


Figure 4-2: Claim trends by work experience group in the sawmill industry of Alberta, Canada from 1997-2000



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Chapter 5 – Injuries and accidents in the plywood manufacturing industry group 1997-2002: A descriptive study of Alberta Workers Compensation Board claims

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5.1 Introduction

In the plywood, chipboard, strandboard and fibreboard manufacturing industry group (plywood manufacturing industry group) of Canada an average of 23,342 person years were worked per year in the period between 1997 and 2001 (Statistics Canada, 2003a,b). During the same period the plywood manufacturing industry group contributed an average of approximately 1.6 billion dollars annually to the national gross domestic product (Statistics Canada, 2003c). Within Alberta alone from 1997-2001, the plywood manufacturing industry group accounted for an average of 2,206 person years worked annually (S.D. 179.4) and generated approximately 0.15% of the provincial gross domestic product based on 2001 data (Reurink, 2003). During the period examined the plywood manufacturing industry group maintained a lost time claim rate an average of 27.3% lower than the provincial average and 58% lower than the forest products manufacturing sub-group average (Alberta Human Resources and Employment, 1998, 1999, 2000, 2001, 2002). Injuries and illnesses in the plywood manufacturing industry group resulted in 831 successful Workers Compensation Board (WCB) claims from 1997 to 2002. The study was performed by analyzing a comprehensive Workers Compensation Board of Alberta dataset of claims occurring in the forestry industries of Alberta. Description of claim trends by accessing the WCB of Alberta's database is currently the most accurate method of describing occupational injury/accident trends in Canada. No detailed information describing workplace injuries/illnesses or the characteristics of those injured within the plywood manufacturing industry group specifically is currently available from either provincial or federal sources. Documents available from federal and provincial sources describe trends in industry subgroups only, in limited detail, and do not describe the characteristics of the individual industries comprising those groups. Further, documents available from provincial and federal sources describe lost time claims only and make no reference to those claims which only result in medical aid. As a method of prioritizing trends observed for intervention the impact of identified injury trends was measured with respect to average and percentage of total cost and duration and compared. As detailed information describing injury trends specific to the plywood manufacturing industry are not available for comparison across provinces, a comparison versus figures reported by the Bureau of Labor Statistics (BLS) in the United States was done as a method of contrasting incidence rates observed.

The plywood manufacturing industry is characterized by high levels of manual materials handling tasks involving primarily the upper extremity. Considerable variation with respect to primary steps in the industrial process is realized between the industries composing the plywood manufacturing group, however the major steps in the process maybe summarized as follows. Logs of varying dimension are transported to the facility from a storage area, cut to size, and debarked with large equipment. Following the input of the dimensional logs into the mill they must be fed into machines where the logs are broken down into the components of the final product, this step in the process requires supervision and occasional heavy manual materials handling. The components of the final wood product, be they wood chips or veneer, are sorted and oriented into the layers of the final product, requiring repetitive manual materials handling using primarily the upper extremity. Maintenance of equipment characterized by varied tasks requiring manual handling of heavy materials with large tools in awkward postures form a major component of the work done in these industrial facilities. Varying degrees of automation are present within and between the industries comprising the industry group.

The objectives of this study were: 1) identify claims trends in terms of nature of injury, type of accident or exposure, source of injury, and body part injured 2) perform analyses to determine the effect of work experience and worker age on the above mentioned classifications 3) assess the impact of observed claims trends in terms of cost and duration of claim 4) compare the overall incidence rates of non-fatal injuries/illnesses generally, and the characteristics of those injuries/illnesses specifically, reported by the Bureau of Labor Statistics to those observed in Alberta between 1997 and 2001.

No peer reviewed literature describing the characteristics of injured/ill workers generally or injuries/illnesses specifically in the wood processing industries of Canada could be located, with the exception of a recent study of the Sawmill industry of Alberta reported by Jones and Kumar in 2004. With respect to epidemiologic studies examining the forestry industry generally and the plywood industry specifically only five studies could be located. Three studies describe only the logging and silviculture industry of New Zealand and not the wood products manufacturing industry sectors (Bentley et al. 2002, Marshal et al. 1994, Macfarlane 1980). Layne and Landen (1997) describe injury characteristics in the forestry industry based on hospital emergency records but provide limited detail with regard to the specific industries comprising the forestry sector. Only the study by Jinadu (1990) describing the 12 month history of workplace accidents in the wood products manufacturing industries of Nigeria presents injury characteristics similar to those described here. A number of studies of cost and duration of work place injury specific to upper extremity and low back workers compensation claims have been performed across industries in the United States, however we were not able to locate such a study describing work related injury occurrence in the forest products manufacturing industries specifically (Zakaria et al. 2003, Courtney et al. 2002, Silverstein et al. 1998, Dempsey and Hashemi 1999, Hashemi et al. 1998, 1997, Webster and Snook 1994).

5.2 Methods

A comprehensive dataset describing claim incidence from 1997 to 2002 was supplied by the Workers Compensation Board (WCB) of Alberta, Canada to the investigators for the purpose of performing a descriptive study on claim trends in the forest products manufacturing industries of Alberta. This study is limited to those descriptive analyses performed on the plywood manufacturing industry group. Within the database coded claim numbers were generated for all claims to protect claimants from identification. Coded account numbers were also generated to protect individual companies operating within the industry from identification. Claims information in the form of original documents (physician's first report, employee's report etc.) were not provided to the researchers in the interests of claimant confidentiality. For this reason a review of claims documents to ascertain the degree of misclassification that exists in the data base examined was not possible. Recurrent incidences of the same injury within individuals were not considered separately as this circumstance resulted in the original claim being reactivated. Multiple activations of the same claim number were therefore considered the same claim. Coding recurrent incidence of same claim this way may inflate the cost and duration of claim, however incidence rates will not be inflated as would be the case in treating each recurrence separately. Multiple claims within the same individual at different time periods were considered separately and included in the description of claim trends. The worker characteristics of age, experience (days worked before injury), and occupation reflect the classification at time of injury. Data allowing the determination of claims cost, duration of claim, and nature of claim (lost time claim versus medical aid only) were controlled by limiting data considered to March 31 of the following year (15 month collection period) to introduce a measure of comparability between the years considered. For this reason only those claims occurring from 1997 to 2000 are considered in mean, median, and standard deviation reported with respect to duration, cost and LTC/MA status. The database supplied by the WCB contained the most detailed coding of the fields reported. The coding system used by the WCB Alberta is identical to those used across compensation boards in Canada and the Bureau of Labor Statistics (BLS) in the United States. A description of specific classifications within the data fields considered (with the exception of occupation classification) is available from the Canadian Standards Association in document Z795-96 (2001). The data field codes were individually considered and grouped by the authors into the categories reported. This was done to facilitate future studies of specific classification incidence within the characteristic groupings (i.e. musculoskeletal injuries) and provide increased detail to the reader. A total of 831 WCB claims occurred in the plywood manufacturing industry group of Alberta from January 1, 1997 to Dec 25, 2002. Both claims classified as medical aid only (MA) and claims classified as lost time (LTC) were included in the database and considered in the claim incidence trends described. LTC claims were defined as those claims which incur compensation and/or pension costs from the date of accident to March 31 of the following year (15 months of costs development). An LTC by WCB definition may not be associated with time-loss, LTCs without time-loss are excluded from BLS/WCB comparisons. A MA claim is defined as a claim that incurred only medical aid costs.

To enable comparison of incidence rates observed in Alberta vs. BLS the coding structure adopted by the BLS was used and incidence rates were averaged across the five years from 1997-2001. Reported Alberta incidence rates were calculated by dividing observed occurrence by person years worked. Total person years worked in the plywood manufacturing industry group was determined by dividing the total insurable earnings in the industry by the average industry wage according to WCB figures. Disparity may exist between the industrial classification systems used by the BLS and the WCB of Alberta. In this study industries 2435, 2436, and 249 (Hardwood veneer and plywood, Soft wood veneer and plywood, and Miscellaneous wood products) as identified by the Standard Industry Classification (SIC) system used by the BLS and industry 27103 (Plywood, chipboard, strand board and fibreboard mills) as identified by Alberta Human Resources and Employment were compared. Because industry 27103 was deemed to comprise 3 industry groups, according to the SIC classification scheme, an average based on the cumulative 5 year averages of the three industries was used for the comparisons reported. Both overall incidence of non fatal injuries and illnesses, and specific injury/illness characteristics (e.g. nature of injury) were compared to non-fatal occupational injury figures reported by the BLS. Alberta claim characteristics incidence rates were adjusted by a factor of 4.53 to enable comparison to BLS figures as an annual average of 2,206 person years were worked annually in the plywood manufacturing industry group of Alberta during the period examined (1997-2002) and BLS incidence data reports incidence rates per 10,000 person years worked. Overall BLS non-fatal occupational injury incidence statistics consider cases without lost work days, cases with restricted work activities only, and cases with lost work days. BLS injury/illness characteristic incidence rates reported by the BLS refer only to those lost work day cases resulting in days away from work. In both comparisons (overall incidence and characteristic incidence rates) all Alberta claim groups (LTC, MA, and total) are reported. It is not possible to separate lost time claims into those resulting in days lost and those resulting in restricted activities only in the case of the Alberta database. Nonfatal occupational injuries reported by the BLS are defined as involving one or more of the following: loss of consciousness, restriction of work or motion, transfer to another job or medical treatment (other than first aid).

5.3 Results

5.3.1 Number of workers employed and total claims incidence

Average number of full time equivalent workers employed in the plywood industry of Alberta from 1997-2001 was estimated by dividing the total insurable earnings in the plywood industry from the average industry wage according to WCB figures. During the five year period described an average of 2,206 person years were worked annually in the plywood industry of Alberta. Comparison of incidence rates of nonfatal occupational injuries and illnesses per 100 person years worked between the WCB Alberta dataset and that presented by the BLS are presented in table 5-1.

5.3.2 Characteristics of the injured workers

No census information was available indicating the characteristics of the total plywood manufacturing group work force. For this reason calculation of relative risk given specific characteristics of the population could not be derived. Males accounted for 79.2% of accepted claims and females for 18.9% of accepted claims in the time period from 1997 to 2002. The 35-44 year old age group experienced the highest proportion of claims at 31.4% followed by the 25-34 year age group at 29.4 % and the 20-24 year age group at 15.3% of the total. The average age at time of injury was 36 years with a standard deviation of 10.63 years. The 2-5 year experience group was involved in the highest proportion of claims at 31.3 % of the total claims followed by the 1-6 month experience group at 16.1% and the 5- 10 years experience group at 13.9% of the total accepted claims. Of the claims described only 37.3% contained data describing the days worked before injury, thus conclusions drawn from interpretation of claim trends may be affected. Claims experience by occupation group as defined by the 1971 National Occupation Classification for the five most frequently occurring occupation titles is presented for the reader in table 5-2 (Dominion Bureau of Statistics, 1971). Within the occupation classification 55.7% of claims provided information on job title. Conclusions drawn from observed trends by occupation classification may therefore be affected.

5.3.2.2 Worker characteristics: Age and experience

The mean cost of claim was observed to increase as age increased. Mean duration of claims was observed to decrease as age increased. The average cost of claim in the 34-64 year age group was 1.57 times greater than that in the 20-34 year age group. Mean duration of claim in the 35-64 yr. age group was 90% that of the 20-34 yr age group. Analysis of percentage of claims by claim characteristic group by age and experience are presented in figures 5-1 and 5-2. Trends illustrated in figure 5-1 are based on the linear regression model normalized to the highest value and excluding groups smaller than 25 in the cases of cost and duration of claims. Claim characteristic trends illustrated in figure 5-1 and 5-2 depict the percentage of claims attributable to the described group by characteristic. The highest proportion of musculoskeletal injuries was observed in the 25-34 and 35-44 year age groups with the proportion of claims classified as MSI in nature falling on either side of these age categories. The proportion of traumatic injuries remained relatively consistent and accounted for a five year average of 12.8% of claims. Two trends observed when analyzing the nature of injury composition of the work experience groups warrant further description. Generally the proportion of musculoskeletal injuries was observed to increase with higher levels of experience. The proportion of musculoskeletal injuries in the 10-15 years experience group was 1.17 times that of the 1 to 6 months experience group. The proportion of wound and traumatic injuries were observed to decrease slightly with increasing experience. Wound and traumatic injuries accounted for an average of 21 and 12 percent of claims respectively across the considered experience categories. With regard to the type of accident or exposure resulting in claim; bodily reaction/exertion was observed to account for an increasing proportion of accident/injury exposure with increasing levels of experience. The proportion of claims attributed to bodily reaction or exertion exposure in the 10-15 year experience group was 2.19 times higher than that of the 1-6 month group.

5.3.3 Claims Characteristics

The WCB database analyzed described each claim with respect to four characteristic categories. Each claim was described in terms of nature of injury (NOI), type of accident or exposure resulting in injury (TOA), part of body injured (POB) and source of injury (SOI). The three leading classification groups and specific classifications by category are presented in table 5-3. The leading classification groupings of musculoskeletal injuries of upper extremity resulting from bodily reaction or motion on parts or machinery is expected due to the manual material handling nature of the industry group. Conclusions drawn from trends observed may be affected by the percentage of claims with information (NOI 96%, TOA 83%, POB 99%, SOI 72%).

5.3.3.2. Comparison of Alberta and BLS Incidence Statistics

Table 5-4 presents a comparison of the incidence rates per 10,000 person years worked for three most frequently occurring classification groupings by characteristics category between the BLS and Alberta, using the classification scheme adopted by the BLS. Large disparities between incidence rates observed in Alberta and those reported by the BLS were identified. Some disparity between observed incidence rates in Alberta to those reported by the BLS are to be expected due to the inability to specifically identify claims resulting in lost time with days away from work.

5.3.4 Cost and duration of claims

The data fields of claim classification (lost time claim vs. medical aid only), total time lost due to injury/accident, and total cost of injury were normalized to include values accumulated to March 31 of the following year only. The figures reported in this section reflect this time period in an effort to control for the confounding effect of different cost/time/etc. accumulation due to duration of the claim at the time of database extraction. Only those claims occurring in the four year period form 1997 to 2000 were considered in the following section to ensure all claims had adequate time to accumulate claims costs etc. Of the claims accepted by the WCB of Alberta, Canada in the plywood manufacturing industry group from 1997 to December 31, 2000, 35.2% incurred compensation and/or pension costs and are therefore considered lost time claims. 64.8% of claims required medical aid costs only and required no time away from work. The median days lost from work due to injury/accident in the plywood manufacturing industry group from 1997 – 2000 was 0 with a standard deviation of 28 days. An average of 1,091 days were lost annually during the period examined due to injury/accident resulting in a WCB claim. The largest claim duration category within the total time lost field was the no time loss category which accounted for 71.2% of all claims. The mean and median cost of claim was $2,181 and $304 respectively. An average annual cost of $ 334,882 was generated due to claims in the plywood manufacturing industry group.

5.3.4.2 Cost and duration of claims: by injury/accident category

Within the nature of injury groupings the categories of poisoning etc., traumatic injuries, and burns accounted for the highest mean cost and mean days lost. Higher mean cost and duration was also reflected in higher lost time claim to medical aid only ratios (LTC / MA). Poisoning claims had the highest severity as measured by the LTC / MA ratio at .75 followed by traumatic injuries at .66. Measuring impact on industry may be more accurately accomplished through determining the percentage of total cost and total days lost attributable to the various nature of injury categories however. In terms of percentage of total time loss and total cost, musculoskeletal injuries accounted for the highest percentage at 52% and 45% respectively. By this criteria the musculoskeletal nature of injury group had the largest impact on the plywood manufacturing group despite ranking fourth in terms of mean cost, mean duration, and LTC/MA ratio due to high occurrence. Traumatic injuries accounted for the second highest proportion of costs at 21% of claims costs followed by wound injuries at 12%. With respect to the type of accident or exposure resulting in claim; exposures due to bodily reaction/exertion were observed 3.16 times more often than caught in injuries. The disproportionate cost and duration of the caught in grouping resulted in the leading percentage of total cost and third leading grouping in terms of percentage of total days lost. The implied greater severity of claims resulting from caught in injuries or exposures is reinforced by the higher LTC / MA ratio of .88 in comparison to the bodily reaction/exertion ratio of .77. The higher overall incidence of bodily reaction/exertion claims resulted in this group ranking first in terms of percentage of overall days lost and second in terms of percentage of overall cost. With respect to the three body part injured groups with highest incidence;

mean cost per claim was highest in lower extremity injuries followed by upper extremity injuries and finally spine/trunk injuries. The lower extremity group accounted for the highest mean duration of claim and highest average number of days lost followed by the spine/trunk and lastly the upper extremity groups. Upper extremity injuries accounted for the overall highest percentage of total cost and days lost due to the large number of injuries. Lastly, with respect to severity measured by the LTC / MA ratio the spine trunk led the three most frequent body part groups at .77 followed by the upper extremity at .49 and the lower extremity at .47. Analysis of the source of injury/accident field revealed that among the three leading source of injury categories injuries/illnesses resulting from parts and machinery resulted in the highest mean cost and duration of claim as well as the greatest percentages of overall cost and days lost. Injuries/illnesses resulting from bodily conditions or motions followed by those injuries/illnesses resulting from tools accounted for the second and third highest mean and percentage of total values across all cost and duration categories respectively. Interestingly among the three most commonly occurring source of injury groupings those resulting form bodily conditions or motions had the highest LTC/MA ratio followed by the parts and machinery grouping and lastly the tool grouping.

5.4 Discussion

This study is the first to detail claim trends in the plywood manufacturing industry group of Alberta, Canada. Review of table 5-3 highlights injury trends anticipated from an industry which requires materials handling in a number of phases within the manufacturing process. Sprain and strain injuries, resulted in 303 (36%) of all successful WCB claims outnumbering all claims falling under the wound classification (204 or 26%) and traumatic injuries (102 or 13%). Cost and duration figures were limited to the first 15 months of claim duration. This was done due to the relatively small overall number of claims per year and the impact of including the 1% of claims accumulating lost time days and costs beyond 15 months. Limiting the claims cost and duration data to a 15 months collection reduced the differences observed between mean and median costs observed. A number of studies examining workers compensation costs and duration of specific body regions and natures of injury have found mean costs and durations to exceed median figures by as much as 23.2 times (Courtney et al. 2002, Dempsey et al. 1999, Hashemi et al. 1998, Hashemi et al. 1997). While we observed skewed cost and duration distributions the effect of limiting cost and duration collection to a 15 month window resulted in a maximum difference between mean and median cost values of 11.8 times in the case of "caught in" injuries. The average difference between mean and median cost values, considering only the top two classification groups, in each claim characteristic category was 5.9. Comparison of mean and median values observed with respect to claims duration is not meaningful as the median distribution of all claims was observed to be 0.

Significant differences exist between the incidence rates reported by the BLS and those observed in the plywood manufacturing industry group of Alberta from 1997 to 2001. Possible explanations for this disparity include fundamental differences in the industry groups, differences in the reporting structure and data collection methodology, differences in the industrial processes of the two countries, and environmental factors. Differences in the industrial groups compared may be addressed in the future through adoption of the North American Industrial Classification System (NAICS) however neither agency currently reports injury statistics based on the NAICS system. Further, comparison of the incidence rates specific to the characteristics of successful WCB claims (e.g. sprains and strains) versus BLS incidence rates is confounded by the inability to separate Alberta lost time claims into those with lost time days and those with days of restricted work activity only. Reported BLS incidence rates examining claims characteristics (i.e. sprains and strains or upper extremity injuries) consider only cases resulting in lost work days. Despite the above limitations the comparisons made serve as an indication of incidence rates observed when all injuries resulting in medical treatment are included in rates described. The observed differences between rates reported by the BLS and those observed in Alberta indicate higher incidence rates given the increased sensitivity of the measurement approach. Other authors have found BLS statistics to considerably underestimate observed incidence rates as well. In a study of the incidence of work related upper extremity disorders Silverstien et al. (1998) observed and incidence rate for disorders associated with repetitive trauma was 2.2 times greater than that reported by the BLS. The comparisons made here serve as an indication of incidence rates of injuries requiring medical aid and how these differ from those requiring time loss only. We believe these comparisons are meaningful given a complete population of claims collected in Alberta was compared to a sample collected from 178,000 employer reports, based on a five year averages, using the same coding structure.

The limitations of this study include, the inability to assess misclassification of claim information by Workers Compensation Board coders due to restrictions in access to the primary claims documents for the purposes of claimant confidentiality. Zakaria et al. 2003 assessed the accuracy of claims coding and found an overall accuracy of 86% with respect to nature of injury and part of body injured classification, as we did not review original claims document we were unable to assess the impact of misclassification. Second the distribution of worker characteristics (gender, age, experience, occupation) within the plywood manufacturing industry is not known. Without this information the determination of relative risk of injury given the characteristics of the work force is not possible.

The strengths of this study include, the studies ability to include the entire population (LTC and MA) of accepted claims occurring in a small industry group over the period examined within a defined industry group, as well as the standardization of claims information due to all claims being collected within the same province under the same administrative database.

5.5 Conclusion

It has been observed that as the age of the worker increases mean cost of claim increases while mean duration of claim decreases. As the number of days worked increases the nature of injury distribution also changes. Those with a greater amount of experience displayed higher proportions of musculoskeletal injuries, a decreasing number of wound injuries and a consistent number of traumatic injuries. The distribution of occupational tasks among the experience groups has not been considered however. Interestingly as the days worked increased so too did the likelihood that the type of exposure resulting in injury/accident will be bodily reaction/exertion/movement. Importantly, given the overall number of healthy workers remains unknown, an increasing proportion of injuries classified in age and experience groups does may not indicate increasing risk.

The predominance of musculoskeletal injuries within this industry suggests intervention strategies directed at the prevention and treatment of musculoskeletal injuries may have the greatest impact on overall claim cost and duration. With regard to the part of body injured upper extremity injuries have demonstrated the greatest impact on overall cost and days lost in the plywood manufacturing industry group followed by the lower extremity and spine/trunk groupings. Again interventions focused on body regions in this order, taking into consideration the type of accident/exposure and the source of the injury, have the greatest potential to reduce injuries and illnesses in the plywood manufacturing industry group. Disparities between the incidence rates of specific injury/illness characteristic categories indicate that the survey of occupational injuries and illness is not an accurate indication of the characteristics of accepted compensation claims in the plywood industry group of Alberta, Canada.

5.6 Acknowledgement

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Table 5-1: Comparison of nonfatal occupational injuries and illnesses incidence rates in the plywood manufacturing industry

		Incidence rate per 100 person years worked	% diff AB vs. BLS
Alberta	LTC & MA	6.26	-25%
	LTC	2.00	-52%
	MA	4.26	3%
BLS	LWC & WLW	8.31	
	LWC	4.16	
	WLW	4.15	

Comparison of nonfatal occupational injuries and illnesses incidence rates in the plywood manufacturing industry. Lost time claims (LTC) and Medical Aid claims (MA) compared to Lost Workday Cases (LWC), including cases with days away from work and cases with restricted work activity only, and Without Lost Workday cases (WLW). Incidence rates are based on the 5 year average 1997-2001 (Bureau of Labor Statistics 2003a).

Table 5-2: Top five occupation classifications by claims incidence in the plywood manufacturing industry of Alberta, Canada from 1997 to 2002.

Rank	**Occupation description**	**Percent of total classified**
1	Industrial/farm/construction machinery mechanics/repairmen	7.5
2	General laborers	6.3
3	General material handling equipment operators	4.6
4	Laborers wood processing except pulp	4.2
5	Construction electricians/repairmen	2.4

Table 5-3: Top three specific classifications by classification group

		Classification groupings			
		Nature of injury	**Type of accident or exposure**	**Part of body injured**	**Source of injury**
Leading classifications and relative % of total classified	**1**	Musculoskeletal injuries (52.4%) ◆ 79.2% Sprains, strains tears ◆ 6.7% Tendonitis ◆ 4.3% Back pain/hurt back	Bodily reaction/exertion/movement (32.7%) ◆ 24.4% overexertion-lifting ◆ 20.9 % overexertion-pulling/pushing ◆ 16.9 % bending/climbing/crawling reaching	Upper extremity (41.8%) ◆ 22.9% fingers except thumb ◆ 18.3% wrist ◆ 11.9% hand except fingers	Parts and machinery (21.6%) ◆ 19.4% Wood/lumber general ◆ 10.6% beam ◆ 6.2% chain
	2	Wound (cut/amputations/other) (25.6%) ◆ 38.7% bruise/contusion ◆ 37.3% cut laceration ◆ 8.3% foreign body	Struck by contact with (25.5%) ◆ 26.2% struck by object ◆ 17.0% struck against object general ◆ 13.1% struck against stationary object	Spine/trunk (19.8%) ◆ 50.9% lower back, unspecified location ◆ 25.2% general back including spine /spinal cord ◆ 12.3% lumbar region	Bodily condition or motion (21.3%) ◆ 100% bodily motion-injured/ill worker classification
	3	Traumatic injuries (12.8%) ◆ 70.6% fractures ◆ 12.7% crushing injuries ◆ 8.8% dislocation	Fall (11.3%) ◆ 29.5% Fall to floor/walkway/other surface ◆ 21.8% Fall onto or against object ◆ 5.1% Fall down steps/stair, fall from ladder, fall from nonmoving vehicle	Lower extremity (17.1%) ◆ 36.2% knee ◆ 25.5% ankle ◆ 12.1% lower leg	Tools-powered/non (14.2%) ◆ 17.3% knife ◆ 9.0% crowbar ◆ 7.4% pick, cart/dolly/hand truck

Table 5-4: Comparison of incidence rates of top three Nature of Injury and Type of Accident or Exposure classifications by BLS classification scheme

	Nature of Injury			Type of accident or exposure						
				Contact with objects				Overexertion		Exposure to harmful substance or environment
	Sprains and strains	Cuts and punctures	Bruises	Total	Struck by object	Struck against object	Caught in or compressed or crushed	Total	In lifting	
*LTC and MA	243.02	69.82	61.66	202.22	84.33	50.78	49.87	125.14	44.43	35.37
LTC	87.05	14.51	15.42	64.38	27.20	10.88	21.76	46.25	21.76	10.88
MA	155.97	55.31	46.25	137.83	57.13	39.90	28.11	78.89	22.67	24.48
**BLS	72.11	29.01	21.30	91.51	37.85	22.74	28.51	51.29	22.29	7.04
% diff [(LTC and MA / BLS -1) x 100]	237%	141%	190%	121%	123%	123%	75%	144%	99%	402%
% diff [(LTC / BLS -1) x 100]	21%	-50%	-28%	-30%	-28%	-52%	-24%	-10%	-2%	55%
% diff [(MA / BLS -1) x 100]	116%	91%	117%	51%	51%	75%	-1%	54%	2%	248%

*LTC and MA – Lost time claim (claims resulting in pension and or compensation costs) / MA – Claims which require medical aid only.
**BLS - Bureau of Labor Statistics – Incidence rates based on 10,000 person years worked taken from Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics 2002b,c 2001b,c 2000b,c 1999b,c 1998b, c).

Table 5-5: Comparison of incidence rates of top three Part of Body and Source of Injury classifications by BLS classification scheme

	Part of body										Source of injury		
	Trunk			Upper extremities				Lower extremities			Parts and materials	Worker motion or position	Hand tools
	Total	Back	Shoulder	Total	Finger	Hand	Wrist	Total	Knee	Foot			
*LTC and MA	201.31	126.95	38.99	211.28	75.26	28.11	45.34	102.47	36.27	13.60	97.93	89.77	46.25
LTC	78.89	51.69	10.88	59.85	17.23	3.63	16.32	29.92	8.16	0.91	37.18	32.64	9.07
MA	122.42	75.26	28.11	151.44	58.04	24.48	29.02	72.54	28.11	12.70	60.76	57.13	37.18
**BLS	71.86	44.94	13.52	71.55	31.52	13.11	13.70	39.11	13.36	9.88	54.25	32.63	12.09
% diff [(LTC and MA / BLS -1) x 100]	180%	182%	188%	195%	139%	114%	231%	162%	171%	38%	81%	175%	282%
% diff [(LTC / BLS -1) x 100]	10%	15%	-20%	-16%	-45%	-72%	19%	-23%	-39%	-91%	-31%	0%	-25%
% diff [(MA / BLS -1) x 100]	70%	67%	108%	112%	84%	87%	112%	85%	110%	28%	12%	75%	207%

*LTC and MA – Lost time claim (claims resulting in pension and or compensation costs) / MA – Claims which require medical aid only.
**BLS - Bureau of Labor Statistics – Incidence rates based on 10,000 person years worked taken from Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics 2002d,e 2001d,e 2000d,e 1999d,e 1998d,e).

Figure 5-1: Claim trends by age group in the plywood manufacturing industry of Alberta, Canada from 1997-2000.

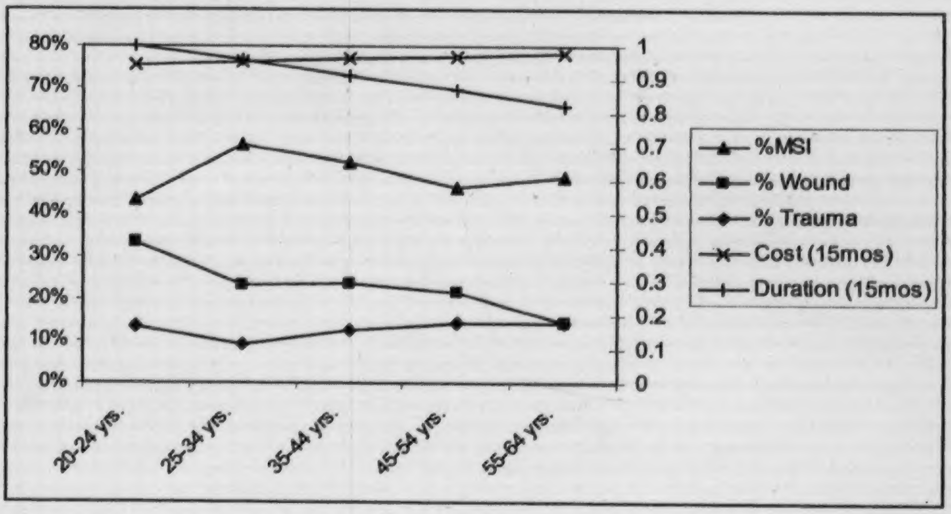
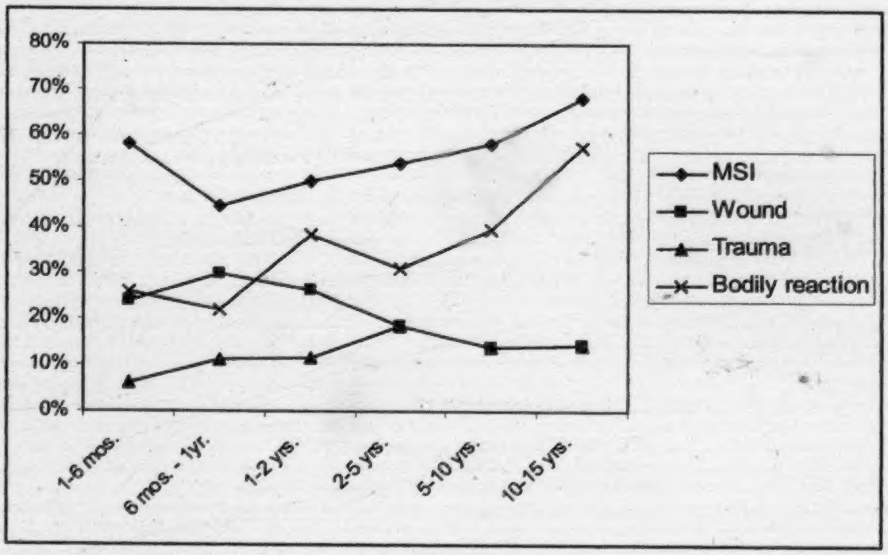


Figure 5-2: Claim trends by work experience group in the plywood manufacturing industry of Alberta, Canada from 1997-2000.



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Chapter 6 – Injuries and accidents in the pulp and paper manufacturing industry group 1997-2002: A descriptive study of Alberta Workers Compensation Board claims

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6.1 Introduction

The pulp and paper manufacturing industry of Canada employed an average of 66,959 workers annually in the period between 1997 and 2001. During the same period the pulp and paper manufacturing industry contributed an average of approximately 8.3 billion dollars to the national gross domestic product (Statistics Canada, 2003a,b). Within Alberta alone the pulp and paper manufacturing industry accounted for an average of 3,448 person years worked and generated approximately 0.46% (542 million dollars) of the provincial gross domestic product in 2001 (Reurink, 2003). The pulp and paper manufacturing industry group maintained a lost time claim rate an average of 72.7% lower than the provincial average and 84.2% lower than the forest products manufacturing sub-group average. Between 1997 and 2002 the pulp and paper manufacturing industry accounted for 645 accepted Workers Compensation Board claims and ranked forth overall in accepted claims in the forest products manufacturing sub-group.

A descriptive analysis was performed of claims incidence within the pulp and paper manufacturing industry of Alberta for the purpose of assisting employers to develop and improve health and safety programs addressing prevention and rehabilitation of workplace injuries. The study was performed by analyzing a comprehensive Workers Compensation Board of Alberta dataset of claims incidence in the forestry industries of

Alberta. Description of claim trends by accessing the Workers Compensation Board of Alberta's database is currently the most accurate method of describing occupational injury/accident trends in Canada. National census data are available in Canada however; census data is not collected in concurrent years and are primarily based on the subjective report of the general population. In addition to the subjectivity of the data the lack of continuous data collection makes it difficult to control for the biasing effects of industry change due to legislation, market, technology, etc. as is somewhat possible when analyzing a sample collected in concurrent years. Data collected by federal agencies describing hospital admissions is also collected federally; however the scope of this data is limited when considering work-place injury/accident trends as many injuries occurring in the work-place do not result in a hospital visit. No detailed information describing workplace injuries/illnesses within the pulp and paper manufacturing industry specifically is currently available from either provincial or federal sources. Documents available from federal and provincial sources describe trends in broad industry subgroups only, in limited detail, and do not describe the characteristics of the individual industries comprising those groups. Further, documents available from provincial and federal sources describe lost time claims only and make no reference to those claims which result in medical aid only. The objectives of this study are: 1) Identify claims trends in terms of nature of injury, type of accident or exposure, source of injury, and body part injured. 2) Determine the effect of work experience and worker age on the above mentioned classifications. 3) Assess the impact of observed claims trends in terms of cost and duration of claim. 4) Compare the overall incidence rates of non-fatal injuries/illnesses, and the characteristics of those injuries/illnesses reported by the Bureau of Labor Statistics to those observed in Alberta between 1997 and 2001.

We could locate no peer reviewed literature describing the characteristics of injured/ill workers generally or injuries/illnesses specifically in the wood processing industries of Canada. With respect to epidemiologic studies examining the forestry industry generally and the pulp and paper industry group specifically only five studies could be located. Three studies describe only the logging and silviculture industry of New Zealand and not the wood products manufacturing industry sectors (Bentley et al., 2002, Marshal et al., 1994, Macfarlane, 1980). Layne and Landen (1997) describe injury characteristics in the forestry industry based on hospital emergency records but provide limited detail with regard to specific industries comprising the forestry sector. Only the study by Jinadu (1990) describing the 12 month history of workplace accidents in the wood products manufacturing industries of Nigeria presents injury characteristics similar to those described here.

6.2 Methods

A comprehensive dataset describing claim incidence form 1997 to 2002 was supplied by the Workers Compensation Board (WCB) of Alberta, Canada to the investigators for the purpose of performing a descriptive study describing claims incidence in the forest products manufacturing industries of Alberta. This paper is limited to those descriptive analyses performed on the pulp and paper manufacturing industry. Within the database coded claim numbers were generated for all claims to protect claimants from identification. Coded account numbers were also generated to protect individual companies operating within the industry from identification. Recurrent incidences of the same injury within individuals were not considered separately as this circumstance resulted in the original claim being reactivated. Multiple claims within the same individual at different time periods were considered separately and included in the description of claim trends. Data allowing the determination of claims cost, duration of claim and nature of claim (lost time claim versus medical aid only) were controlled by limiting data considered to March 31 of the following year to introduce a measure of comparability between the years considered. The database supplied by the WCB contained the most detailed coding of the fields reported possible. The coding system used by the WCB Alberta is consistent with those used across compensation boards in Canada and the Bureau of Labor Statistics in the United States. A description of specific classifications within the data fields considered (with the exception of occupation classification) is available from the Canadian Standards Association in document Z795-96 (2001). The data field codes were individually considered and grouped by the authors into the categories reported. This was done to facilitate future studies of specific classification incidence within the characteristic groupings (i.e. musculoskeletal injuries) and provide increased detail to the reader. A total of 645 WCB claims occurred in the pulp and paper manufacturing industry of Alberta from January 1, 1997 to Dec 25, 2002. Both claims resulting in medical aid only (MA) and claims resulting in lost time (LTC) were included in the database and considered in the claim incidence trends described. LTC claims were defined as those claims which incur compensation and/or pension costs from the date of accident to March 31 of the following year (15 months of costs development). An MA claim is defined as a claim that incurs medical aid costs only. Canadian employment and gross domestic product figures (provincial and national) are estimated as a disparity between the industry classification system used by the WCB of Alberta and that used by provincial and federal agencies (North American Industrial Classification System) is possible. Age of the injured worker was reported at the time of injury and experience is reported as days worked up to the report of injury/illness. To enable comparison of injury characteristics vs. BLS statistics the coding structure adopted by the BLS was used to re-categorize the specific classifications and enable comparison between the comprehensive WCB data set and that based upon the Survey of Occupational Injuries and Illnesses performed by the BLS annually. The incidence of the specific characteristic groups was averaged across the five year period from 1997-2001 and compared. Some disparity may exist between the industrial classification systems used by the BLS and the WCB of Alberta. In this study the five year incidence rate averages of industries 261, 262, and 263 (Pulp mills, Paper mills, and Paperboard mills) as identified by the Standard Industry Classification used by the BLS and industry 27102 (Pulp mills including; conversion of wood to pulp, manufacture of news print, leached kraft pulp mills, and chemithermomechanical pulp mills) as identified by Alberta Human Resources and Employment were compared. Because industry 27102 was deemed to comprise 3 industry groups, according to the SIC classification scheme, the five year average based on the cumulative 5 year averages of the three industries was used for the comparisons reported. Both overall incidence of non fatal injuries and illnesses, and specific injury/illness characteristics (e.g. nature of injury) were compared according to the groupings specified by the Bureau of Labor Statistics. With respect to the comparisons of specific injury characteristic groups, WCB data set figures were adjusted by a factor of 2.8998 to arrive at incidence rates per 10,000 person years worked and enable comparison to BLS figures. With regard to comparisons of incidence rates of the characteristics of injuries/illnesses, BLS incidence rates describe lost work day cases resulting in days away from work only (not including those which required restricted work activity only). BLS incidence data reported are based on non-fatal occupational injuries and are defined as involving one or more of the following: loss of consciousness, restriction of work or motion, transfer to another job or medical treatment (other than first aid).

6.3 Results

6.3.1 Number of workers employed and total incidence of claims

The average number of person years worked in the pulp and paper manufacturing industry from 1997 to 2001 was estimated by dividing the total insurable earnings in the pulp and paper industry from the average wage in the industry according to WCB figures. During the five year period described an average of approximately 3,448 person years were worked in the pulp and paper industry of Alberta. Comparison of incidence rates of nonfatal occupational injuries and illnesses per 100 person years worked between the WCB Alberta dataset and that presented by the BLS is presented in table 6-1.

6.3.2 Characteristics of the injured workers

Males accounted for 86.5% of accepted claims and females for 12.2% of accepted claims in the time period from 1997 to 2002. The 35-44 year old age group experienced the highest incidence of claims at 40.7% of claims followed by the 45-54 year age group at 26.2 % and the 25-34 year age group at 19.9% of the total. The average age at time of injury was 41 years with a standard deviation of 10.2 years. The number of days worked previous to experiencing the injury/accident that resulted in an accepted claim was highest in the 5-10 year experience group at 34.0 % of the total claims followed by the greater than 20 years experience group at 15.2% and the 2-5 year experience group at 13.1% of the total accepted claims. Of the claims described only 37.8% contained data describing the days worked before injury, thus conclusions drawn from interpretation of claim trends may be affected. Claims experience by occupation group as defined by the National Occupation Classification (1971) of the five most frequently occurring occupation titles and their relative percentage are presented for the reader in table 6-2.

Within the occupation classification 59% of claims provided information on job title. Conclusions drawn from observed trends by occupation classification may therefore also be affected.

6.3.3 Claims characteristics

The WCB database analyzed described each claim with respect to four characteristic categories. Each claim was described in terms of nature of injury (NOI), type of accident or exposure resulting in injury (TOA), part of body injured (POB) and source of injury (SOI). The three leading classification groups and specific classifications by category are presented in table 6-3. Conclusions drawn from trends observed may be affected by the percentage of claims with information (NOI 98%, TOA 86%, POB 99%, SOI 78%).

6.3.4 Comparison of Alberta and BLS incidence statistics

Table 6-4 presents a comparison of the incidence rates per 10,000 person years worked for three most frequently occurring classification groupings by characteristics category between the BLS and Alberta, using the classification scheme adopted by the BLS.

6.3.5 Cost and duration of claims

The data fields of claim classification (lost time claim vs. medical aid only), total time lost due to injury/accident, and total cost of injury were normalized to include values accumulated to March 31 of the following year only. The figures reported in this section reflect this time period (1997-2000) in an effort to control for the confounding effect of different cost/time/etc. accumulation due to duration of the claim at the time of database extraction. Of the claims accepted by the WCB of Alberta, Canada in the pulp and paper manufacturing industry from 1997 to 2000, 29.1% incurred compensation and/or pension costs and are therefore considered lost time claims. In Alberta 70.9% of claims resulted in medical aid costs only and required no time away from work. The mean days lost from work due to injury/accident in the pulp and paper manufacturing industry from 1997 – 2000 was 4.63 days lost with a standard deviation of 17.63 days. An average of 540 days were lost annually during the period examined due to injuries/illnesses resulting in claim. Inspection of the claim duration categories reveal that no time was lost in 76.2% of all claims. The mean cost of claims was $1,359 with a standard deviation of $4,399. The median cost of claim was $307. The average annual claim cost of $158,695 was generated in the pulp and paper manufacturing industry in the period examined.

6.3.6 Worker characteristics: Age and experience

No census information was available indicating the characteristics of the total pulp and paper manufacturing work force. For this reason calculation of relative risk given specific characteristics of the population could not be derived. The distribution of age within occupation groups has therefore not been accounted for and is taken to be an important limitation of this study. Physical exposure given required job demands (specific to occupation) will vary significantly among age groups given the tendency towards supervisory work at higher ages. Thus observed differences in nature of injury groupings among age and experience groups may be largely due to the variability in occupations (tasks) those groups are performing. Figures 6-1 and 6-2 describe the observed differences between age and experience groups respectively. Cost and duration of claim trends illustrated in figure 6-1 are based on the linear regression model normalized to the highest value and excluding groups smaller than 25. Nature of injury and body part injured trends illustrate the percentage of claims attributable to the described group.

6.3.7 Cost and duration of claims: by injury/accident category

Within the nature of injury groupings the categories of traumatic injuries and poisoning accounted for the highest mean cost and mean days lost. Higher mean cost and duration is also reflected in higher lost time claim to medical aid only ratios (LTC / MA). Poisoning claims had the highest severity as measured by the LTC / MA ratio at 1.13 followed by traumatic injuries at 1.04. Measuring impact on industry may be more accurately accomplished through determining the percentage of total cost and total days lost attributable to the various nature of injury categories however. In terms of percentage of total cost, musculoskeletal injuries accounted for the highest percentage at

53% of total cost. By this criterion musculoskeletal injuries had the largest impact on the pulp and paper industry despite ranking fifth in terms of mean cost, fourth in terms of mean duration and last (sixth) with respect to severity as measured by the LTC/MA ratio, among the nature of injury categories, due to high incidence. Traumatic injuries accounted for the second highest proportion of costs at 20% of claims costs followed by wound injuries at 16%. Total incidence continues to be the most important indicator of percentage of total cost and total days lost when analyzing the type of accident or exposure field. The type of exposure categories with highest overall incidence account for the highest percentage of costs and days lost. Again the categories associated with traumatic type injuries (i.e. caught in vs. bodily reaction/exertion) are associated with higher mean claim costs and days lost, and higher lost time claim to medical aid ratios (LTC to MA). With respect to body part injured mean cost per claim and duration of claim was highest in lower extremity injuries followed by upper extremity injuries and finally spine/trunk injuries. Lower extremity injuries accounted for the highest percentage of total cost followed by upper extremity injuries and lastly spine/trunk injuries. Percentage of total days lost was highest in the upper extremity followed by the lower extremity and lastly the spine/trunk. In terms of severity of injury measured by the LTC / MA ratio, injuries to the lower extremity were most likely to result in time away from work at .47 followed by spine/trunk injuries at .43 and upper extremity injuries at .38. Analysis of the source of injury/accident field again revealed the source of injury more likely to result in traumatic type injuries (injuries/illnesses due to machinery) were associated with higher mean claims costs and days lost (also reflected in higher LTC to MA ratios) while overall percentage of claims costs and days lost were largely influenced by overall incidence.

6.4 Discussion

6.4.1 Worker characteristics

Conclusions regarding the relative risk of specific worker populations are not possible given no information is collected on the industry workforce as a whole. Additionally, occupation descriptions available describe groups of specific occupations only and the classification scheme used has not been updated since 1971. These limitations make the identification of specific worker groups for intervention based on age, experience, gender, or specific occupation difficult. The strength of conclusions drawn are further compounded by the percentage of claims with information on worker experience and occupation, 38% and 59% respectively. As musculoskeletal injures were observed to be the most frequently occurring nature of injury and the cumulative effect of physical exposures related specifically to occupation and duration of employment (experience) are deemed to be important factors in their incidence, the limited information in these data fields is taken to be a very important limitation of the database examined.

6.4.2 Comparison of WCB and BLS incidence rates

Significant differences exist between the incidence rates reported by the BLS and those observed in the pulp and paper manufacturing industry of Alberta from 1997 to 2001. Possible explanations for this disparity include fundamental differences in the industry groups, differences in the reporting structure and data collection methodology, differences in the industrial processes of the two countries, and environmental factors. Differences in the method of determining person years worked between Alberta figures and BLS figures may contribute substantially to differences in incidence rates. Person years worked in Alberta were determined by total insurable earnings divided by average industrial wage and averaged over five years and adjusted for comparison to BLS incidence rates, BLS data is based on total hours worked by employees during the calendar year. The method used in Alberta may underestimate hours worked by low hourly wage earners and thus over express injury/illness trends in this population. The authors are confident that the comparisons are valid however, given a complete population of claims collected in Alberta was compared to a sample collected from 178,000 employer reports, based on five year averages, using the same coding structure.

6.5 Conclusion

It has been demonstrated from the above analyses that as the age of the worker increases mean cost and duration of claim also increases. As the number of days worked increases the nature of injury distribution also changes. Those with a greater amount of experience displayed higher proportions of musculoskeletal injuries and a decreasing number of wound and traumatic injuries. Interestingly, as the days worked increased so too does the likelihood that the source of injury/accident will be the result of exposure to environmental factors. These experience trends suggest the role of cumulative load in the precipitation of musculoskeletal injuries within this industry should be examined. As well, the effect of worker experience in safe and efficient performance of industrial tasks resulting in less wounds and traumatic injuries should be examined. The distribution of occupational tasks among the experience groups has not been considered however, and the relative percentage of claims with information must be considered in conclusions drawn. The predominance of musculoskeletal injuries within this industry suggests intervention strategies directed at the prevention and treatment of musculoskeletal injuries may have the greatest impact on overall claim cost and duration. With regard to the part of body injured, lower and upper extremity injuries have demonstrated the greatest impact on the pulp and paper manufacturing industry followed by the spine/trunk. Again interventions focused on body regions in this order, taking into consideration the type of accident/exposure and the source of the injury, have the greatest potential to reduce injuries/illnesses in the pulp and paper manufacturing industry. Large disparities between the incidence rates of specific injury/illness characteristic categories indicate that the survey of occupational injuries and illness is not an accurate indication of the characteristics of accepted compensation claims in the pulp and paper industry group of Alberta, Canada.

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Table 6-1: Comparison of nonfatal occupational injuries and illnesses incidence rates in the pulp and paper manufacturing industry

		Incidence rate per 100 person years worked	% diff AB vs. BLS
Alberta	LTC & MA	3.288	-34%
	LTC	0.957	-59%
	MA	2.311	-13%
BLS	LWC & WLW	4.98	
	LWC	2.335	
	WLW	2.645	

Comparison of nonfatal occupational injuries and illnesses in the pulp and paper manufacturing industry. Lost time claims (LTC) and Medical Aid claims (MA) compared to Lost Workday Cases (LWC), including cases with days away from work and cases with restricted work activity only, and Without Lost Workday cases (WLW). Incidence rates are based on the 5 year average 1997-2001 (Bureau of Labor Statistics 2003a).

Table 6-2: Top five occupation classifications by claims incidence in the pulp and paper manufacturing industry of Alberta, Canada from 1997 to 2002.

Rank	**Occupation description**	**Percent of total classified**
1	Industrial/farm/construction machinery mechanics/repairmen	14.9
2	General laborers	3.7
3	Welders/flame cutters wire	3.3
4	General forestry logging occupations	2.8
5	Pipe fitters/plumbers/related fields	2.5

Table 6-3: Three most frequently occurring specific classifications by groupings

		Classification groupings			
		Nature of injury	**Type of accident or exposure**	**Part of body injured**	**Source of injury**
Leading classifications and relative % of total classified	1	Musculoskeletal injuries (54.0%) ♦ 80.6% Sprains, strains tears ♦ 3.8% Tendonitis ♦ 3.0% Soreness pain/hurt except back	Bodily reaction/exertion/movement (33.4%) ♦ 23.8% overexertion ♦ 17.3 % overexertion-lifting, overexertion-pulling/pushing	Upper extremity (31.8%) ♦ 26.6% shoulder including clavicle, scapula ♦ 15.3% elbow ♦ 14.3% fingers except thumb	Bodily condition or motion (24.1%) ♦ 99.2% bodily motion-injured/ill worker classification
	2	Wound (cut/amputations/other) (17.5%) ♦ 40.9% bruise/contusion ♦ 28.2% cut laceration ♦ 12.7% foreign body	Struck by contact with (18.2%) ♦ 18.8% struck against stationary object ♦ 17.9% struck against object general ♦ 15.8% struck by falling object	Spine/trunk (21.3%) ♦ 57.4% lower back, unspecified location ♦ 24.2% general back including spine /spinal cord ♦ 7.4% lumbar region	Parts and machinery (18.6%) ♦ 8.7% plate/metal panel and the valve/nozzle ♦ 6.5% chain ♦ 5.4% beam and pipe/duct/tubing
	3	Traumatic injuries (10.2%) ♦ 60.9% fractures ♦ 20.3% crushing injuries ♦ 9.4% dislocation	Exposure to environment (15.7%) ♦ 29.9% exposure to noise over time ♦ 20.6% inhalation of substance general ♦ 16.1% contact with hot object/substance, contact with skin, eye(s) or other category	Lower extremity (16.0%) ♦ 39.2% knee ♦ 31.4% ankle ♦ 7.8% lower leg	Structure or surface (14.2%) ♦ 17.3% floor/walkway ground surface ♦ 17.1% ground classification ♦ 8.6% door

Table 6-4: Top three most frequently occurring specific classifications by classification group according to BLS classification scheme. Alberta WCB (LTC and MA) claims incidence vs. Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses, lost work day cases only, with days away from work (Bureau of Labor Statistics, 2003b)

Classification grouping	**Nature of Injury**			**Type of accident or exposure**						
	Sprains and strains	**Bruises**	**Fractures**	**Contact with objects**				**Overexertion**		**Exposure to harmful substance or environment**
				Total	**Struck by object**	**Struck against object**	**Caught in or compressed or crushed**	**Total**	**In lifting**	
Alberta LTC and MA	139.2	23.2	19.1	75.4	27.3	23.2	18.6	65.5	18.6	45.8
Alberta LTC	37.1	5.2	7.5	21.5	9.9	5.8	4.6	19.7	7.5	16.8
Alberta MA	102.1	18.0	11.6	53.9	17.4	17.4	13.9	45.8	11.0	29.0
BLS LWC	54.2	12.1	13.0	41.2	17.0	10.4	12.6	28.7	10.0	9.4
% diff LTC and MA	257%	192%	148%	183%	160%	222%	147%	228%	186%	488%
% diff LTC	68%	43%	58%	52%	58%	56%	37%	69%	76%	179%
% diff MA	188%	149%	89%	131%	102%	167%	110%	160%	110%	309%

Classification Grouping	**Part of Body**									**Source of Injury**		
	Head		**Trunk**			**Upper extremities**				**Worker motion or position**	**Parts and materials**	**Floor, walkways or ground surfaces**
	Total	**Eyes**	**Total**	**Back**	**Shoulder**	**Total**	**Finger**	**Hand**	**Wrist**			
Alberta LTC and MA	51.0	15.7	126.4	71.3	29.0	75.4	22.6	8.1	12.2	59.7	47.6	23.2
Alberta LTC	13.9	5.2	38.9	20.3	7.5	19.1	6.4	2.3	4.1	16.2	15.7	10.4
Alberta MA	37.1	10.4	87.6	51.0	21.5	56.3	16.2	5.8	8.1	43.5	31.9	12.8
BLS LWC	5.7	5.8	43.8	30.7	10.1	32.0	12.6	5.8	6.2	28.7	16.9	15.1
% diff LTC and MA	899%	268%	289%	232%	288%	236%	179%	140%	196%	208%	281%	154%
% diff LTC	245%	89%	89%	66%	75%	60%	51%	40%	65%	57%	93%	69%
% diff MA	653%	179%	200%	166%	213%	176%	129%	100%	131%	151%	188%	85%

Figure 6-1: Claim trends by age group in the pulp and paper manufacturing industry of Alberta, Canada from 1997-2002

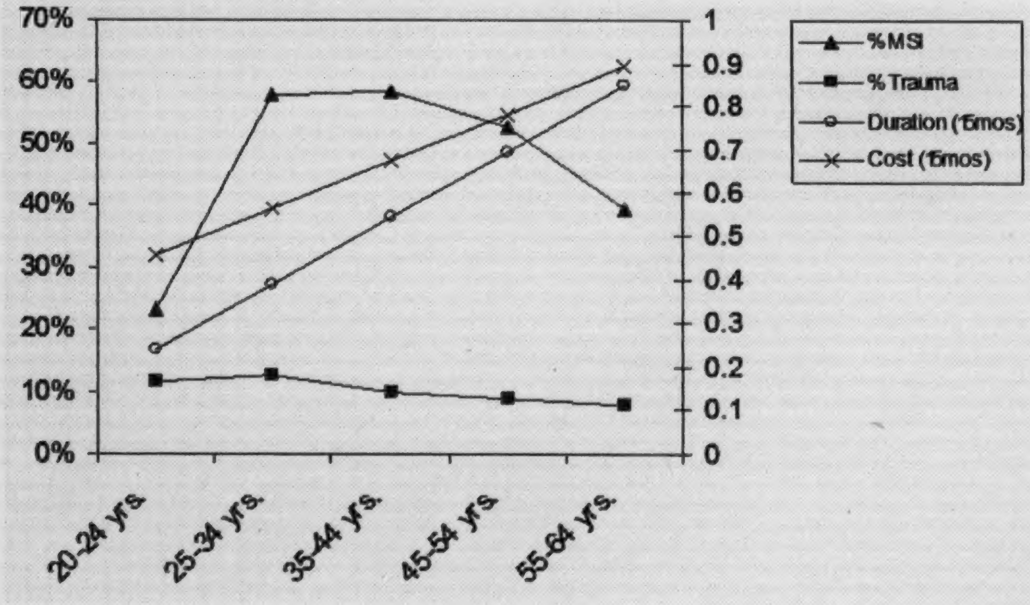
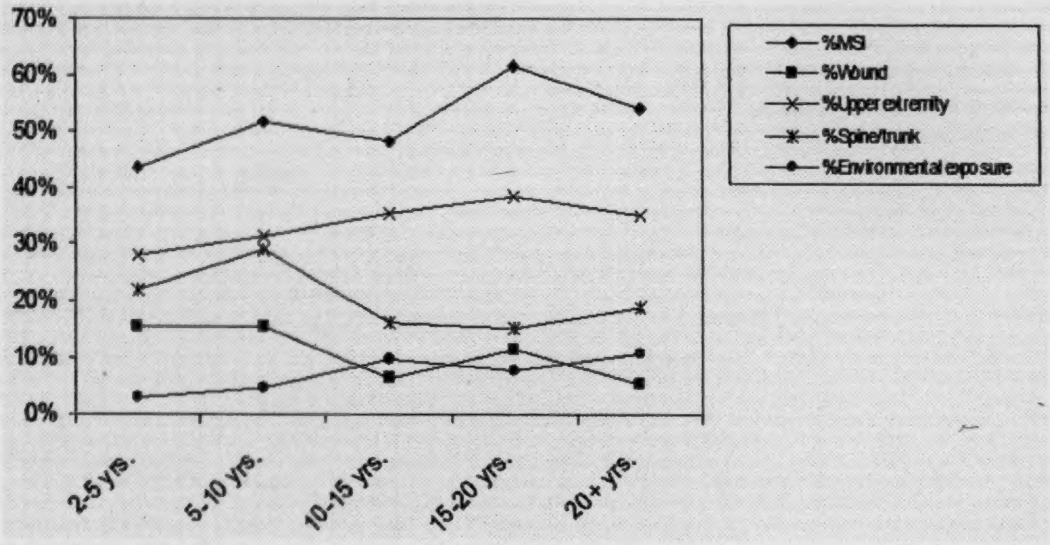


Figure 6-2: Claim trends by work experience group in the pulp and paper manufacturing industry of Alberta, Canada from 1997-2002



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Phase 1 Summary: Retrospective analysis of Workers Compensation Board data

Prior to the studies which comprise chapters 4, 5, and 6 no information had been presented which described injury and illness trends specific to the industries examined in the province of Alberta, Canada. The impact of each injury / illness category was investigated in phase one by examining the percentage of claims in each category and the percentage of the total cost of claims (TCC) and total time lost due to claim (TTL) attributable to each category. In all industries examined musculoskeletal injuries (MSIs) accounted for largest overall percentage of claims and highest percentage of TCC and TTL. The percentage of claims categorized as MSIs by industry as well as the impact of MSIs on the industry (TCC and TTL) is described for the reader in table P1-1.

As described in the third chapter of the thesis, a state of disagreement currently exists between authors of ergonomic risk assessments as to the best method of assessing risk of MSI. Given this state of disagreement a research plan was composed which would compare the predictive validity of multiple assessments for the purpose of identifying the assessment best suited for use in MSI prevention initiatives in the industries examined. As described in chapter 3, ergonomic risk assessments are designed to predict risk of MSI associated with a specific body region. In all industries examined the upper extremity was identified as the most frequently injured body region and thus methods focused on the upper extremity were selected for comparison. In order to examine the methods' ability to predict risk, accurate risk assessment scores are compared to information describing the incidence of injury within specific occupations (morbidity information). Defining the rate of incidence of musculoskeletal injuries within an occupation requires the number of injuries occurring within an occupation be identified and divided by a measure of exposure (e.g., total number of workers present in the occupation). Defining rate of incidence of injury was complicated in these studies due to the inability to: identify specific occupations based on a standardized format and the lack of reliable information describing the entire workforce. It was not possible to identify specific occupations because occupation information collected by the WCB is not present for a significant number of claims and occupation titles present in the WCB dataset were based on a classification scheme which did not represent job titles currently in use within industry. It was not possible to derive accurate morbidity information because information describing the number of workers within each occupation is not collected by standardized means in Alberta, Canada. Regardless of the limitations observed in the standardized (comparable across employers) occupational health information available, it remained necessary to identify occupations at increased risk of injury for examination and approximate the incidence of injury within those occupations. For this reason the occupational health records of the individual facilities participating in the second and third phases of research were consulted to determine which production occupations were commonly associated with MSI to the upper extremity. Facility specific human resources information was also used to derive a measure of exposure enabling calculation of incidence rates. Based on the limitations of the standardized occupational health information available in phase one of the project the analyses planned for the second and third phases were adjusted to focus on the impact of exposure variable definition on the methods and the comparison of risk output between methods.

Table P1-1: % of claims classified as musculoskeletal disorders by industry

Industry	% of claims classified as MSIs	Rank	% of TCC	% of TTL
Sawmill	46.7%	1	33	38
Plywood	52.4	1	52	45
Pulp and paper	54.0	1	53	46

Chapter 7 – Assessment of physical demands and comparison of multiple exposure definitions in a repetitive sawmill job: board edger operator

A version of this chapter has been accepted for publication in the journal Ergonomics.

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7.1 Introduction

In 2003 a comprehensive Workers Compensation Board data set of 3,779 compensation claims was reviewed to identify and describe injury trends affecting the Sawmill industry of Alberta, Canada (Jones and Kumar 2004a). During the period of the review (1997-2002) musculoskeletal injuries accounted for 33% of the total cost and 38% of total time lost due to claim, more than any other injury category. The upper extremity was more frequently involved in compensation claims of a musculoskeletal nature than any other body region. Upper extremity musculoskeletal injuries (UEMSI) resulted in 1,698 successful Workers Compensation Board Claims between 1997 and 2002.

The role of physical exposures in the causation of UEMSIs has been established (US Department of Health and Human Services 1997). Having become aware of this relationship industrial prevention efforts often look to ergonomists applying observational ergonomic risk assessment techniques to identify problem exposures and direct intervention. Ergonomic risk assessments seek to account for the role of the physical exposures in the precipitation of UEMSI by considering the integrated role of the exposures in a model of injury precipitation. Unfortunately, little agreement currently exists between authors in terms of both the physical exposures which should be considered, and the relative role of the exposures in the precipitation of UEMSI (Jones and Kumar 2004b). As a result of this disagreement there is a need to examine the comparability of the different techniques and their association to incidence of injury. Valid application of an ergonomic risk assessment requires an accurate and reliable assessment of physical exposures. Physical exposure assessments which precede an ergonomic assessment of risk are traditionally performed based on observation. A number of studies are now present which describe the measurement error resulting from exposure assessment based on observation. Lowe (2004) examined the ability of worksite evaluators to correctly classify forearm and wrist posture and found rates of misclassification ranged from 22 to 70% when compared to measurements made by electrogoniometers. Bao et al. (2006) found limited correlations between frequency classifications made by ergonomists based on observation and measurements based on detailed time studies. The implication of misclassifying variables considered in the risk assessment is the inappropriate assignment risk level and/or incorrect identification of problem exposures for intervention. The compound effect of measurement error due to observation in multiple elements of the exposure assessments suggests quantified measures are needed. Quantified exposure information will allow meaningful comparisons of observational ergonomic risk assessment techniques by reducing measurement error. No studies could be located which compared the results of multiple risk assessment techniques based on quantified measures.

Ergonomic risk assessment techniques may be applied based on multiple definitions of the posture and exertion variables. Based on observation the worksite evaluator may define posture according to the peak posture observed, peak posture required in the primary task only, or most frequently occurring posture. Quantification of postures required with electrogoniometers allows the comparability of the definitions of posture available in observation based exposure assessments to be examined. Similar to posture, several ergonomic risk assessment techniques allow the evaluator to describe the exertion required to perform the job either in terms of muscle activity or psychophysical perception (Moore and Garg 1995, Occhipinti 1998, University of Michigan 2005). Collection of %MVC required with surface electrogoniometry and the workers assessment of perceived exertion allows the effect of substituting variable definitions on ergonomic risk assessment techniques to be examined. No studies could be located which sought to describe the effect of substituting variable definitions on ergonomic risk assessment techniques. An examination of the effect of multiple definitions on the output of ergonomic risk assessment techniques is necessary to gain insight into optimal definition of the variables.

It is the intent of this paper to describe the physical exposures required to perform high risk sawmill job tasks based on definitions of exposure available to worksite evaluators performing an observation based exposure assessment. Definitions of posture and exertion used were also adopted to reflect those required to perform ergonomic risk assessments. A subsequent paper will use the physical exposure information described here to examine the comparability of multiple risk assessment techniques and the effect of exposure variable definition on those techniques. Electrogoniometers and surface electromyography were used to reducing measurement error. Differences in exposures between facilities were examined in an effort to explain meaningful differences in recorded incidence rates between facilities. The board edger position was selected for further evaluation, given the high number of UEMSIs recorded by the occupational health records of the facilities examined.

The objectives of this study are to: 1) Describe the physical exposures in a sawmill job with high incidence of UEMSIs by multiple posture, exertion and frequency variable definitions. 2) Examine the comparability of those multiple variable definitions.

Few studies are available which describe MSI incidence, either specific to the upper extremity or across body regions, in the forest products manufacturing industries. Silverstien and Hughes (1996) described the occurrence of musculoskeletal disorders in one pulp and paper manufacturing facility. Jones and Kumar (2004a,2004c,2005) described injury and illness trends in the pulp and paper, plywood and sawmill industries in Alberta Canada. Jinadu (1990) described the 12 month history of injuries in the wood products manufacturing industries of Nigeria. No studies could be located which presented quantified physical demands or compared the results of multiple physical exposure variable definitions in this population.

7.2 Methods

7.2.1 Occupation identification

Deriving incidence rates for the board edger position using compensation information was not possible given information describing the complete work force was not available (Jones and Kumar 2004a). For this reason the occupational health records, specific to job, of two sawmill facilities were consulted to determine which production positions were commonly associated with injuries of musculoskeletal nature to the upper extremity. Based on the above criteria the board edger position was selected.

7.2.2 Task description

The board edger position is a repetitive job responsible for sorting boards cut in rough depth dimension immediately after logs have been cut to square dimension and divided into multiple boards. Sorting of the boards involves frequent turning (about the long axis) of boards to position the board with the round side (cant) up for further processing (figure 7-1). Turning boards is the primary task of the board edger; however, he/she may also be required to push, pull and lift boards (position boards) to cause them to fall to conveyors below. Width, length and weight of boards vary by dimension of the log processed.

7.2.3 Subject selection

Workers presently performing the board edger position between the ages of 18 and 65 were recruited at two sawmill facilities. Subjects were excluded from the study if they reported; injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. No female workers were present at the two facilities examined. 16 male subjects volunteered to take part in the study out of the population of 16 (100% participation rate). Complete data sets enabling analysis were collected for 14 of 16 subjects.

7.2.4 Body part discomfort survey (Corlett et al. 1976)

Each worker was asked to complete a body part discomfort survey prior to beginning data collection. Workers were provided a body map and asked to indicate any areas where discomfort is typically felt following a shift using the scale provided. Ratings ranged from 1 (indicating no discomfort) to 10 indicating the body region was "very uncomfortable". Ratings greater than 1 were taken to indicate discomfort.

7.2.5 Data collection

Data collection took place both on and off the production line. Both posture and motion trails and surface electromyography trials were performed by all subjects. Posture and motion information was collected during job performance on the production line. Static surface electromyography trials were performed in a location removed from the production line (e.g. coffee room).

7.2.5.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to turn boards (task dominant upper extremity). Motion and posture of the wrist and distal radio-ulnar joint required to perform the primary task were assessed with Biometrics™ bi-axial SG-65 and uni-axial Q-150 electrogoniometers centered on the wrist joint. Electrogoniometers were applied as per the users' manual recommendations (Biometrics™ 2002). Prior to beginning data collection the subjects were asked to position their elbow at 90 degrees, their forearm in mid position (thumb positioned superiorly), and wrist in neutral position while the electrogoniometers were zeroed. A sample of 5 minutes was recorded during actual job performance. Angular displacement was recorded in 3 planes (X,Y,Z) with synchronized bi-axial and uni-axial Biometrics ™ electrogoniometers at 200 Hz. Postures and frequencies required to perform the job were determined through analysis of the recorded wave forms with the Biometrics Data link analysis software.

7.2.5.2 Exertion data acquisition

Surface electromyography (EMG) was used to assess the muscle activity required to perform maximum voluntary contraction and job simulated exertions. Only the upper extremity reported by the subjects as primarily used to turn boards was assessed. The flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), and flexor digitorum superficialis (FDS) were assessed for the flexion component and the pronator terres (PT) was evaluated for the pronation component of the board flip task. Electrode placement was determined by isolating the muscle in question with manual muscle testing performed by a physical therapist and placing the electrode in approximately the midpoint of the muscle belly. A Delsys Bagnoli 8 EMG system was used. Single differential bipolar electrodes with bar shaped silver detection surfaces (1 cm length x 1mm width) spaced 1 cm apart were used in the experimental trails and oriented perpendicular to the muscle fibers. EMG signals were filtered to consider only those frequencies between 20 and 450 Hz. The data acquisition system consisted of an analog-to-digital board with a 100-kHz sampling capacity. The EMG channels (4) were sampled at 1 kHz in real time. The sampled signals were stored on a laptop computer. Data acquisition took place during a 9 second sample to cover the entire task cycle. 2 seconds prior to the assessors instructions to begin were used to record a baseline activity and 2 seconds following the 5 second test were used to allow the subject to return to baseline values. Experimental trials are administered in random order to allow differences observed to be attributed to differences in the experimental conditions and not the order of trials. Two trials are performed for each condition with the second condition being recorded to allow for a training effect.

7.2.5.2.1. Maximum voluntary contraction: During the MVC trials the subject was seated with the task dominant upper extremity positioned at the side and the elbow bent to 90 degrees. A handle made from a piece of dimensional lumber connected to an immobile base by a steel cable was either rotated (pronation exertion) or elevated (flexion exertion) dependent upon the trial. During flexion trials the steel cable was connected to the middle of the handle and the subject was instructed to perform a wrist flexion exertion. During the pronation trail an alternate handle to which the steel cable was attached to the outside edge was used and the subject was instructed to exert a rotational exertion on the handle. During MVC trials the subject was instructed as follows: "When I say go, I want you to bring your force up to your maximum level over 2 seconds and hold for 3 seconds or until I say stop." The subjects were given a rest period of a minimum of two minutes between trials.

7.2.5.2.2 Job simulated trial. Job simulated trials were performed in a location removed from the industrial process (e.g. lunch room) within the facility. Job simulated muscle activity was determined by having the subject maintain a representative board (5.1 cm. deep by 20.3 cm. wide, 488 cm. long) in a job simulated standardized static position.

Representative board weights upon which the job simulated MVC testing was performed varied from 16.4 to 19.1 kgs. due to varying moisture content. Subjects were tested in standing position with the wrist in neutral flexion/extension and supinated position (job simulated flexion) or slightly pronated from full supination position (job simulated pronation). The height of the mock up table was adjusted such that the subject maintained the board at an angle of approximately 3 degrees from the horizontal plane of the mock up table at 90 degrees of elbow flexion (figure 7-2). In job simulated trials the weight of the representative board was supported by the assessor until the trial was begun. After the trial was begun the weight of the representative board was given to the subject and maintained for approximately 5 seconds until removed by the assessor.

7.2.5.2.3 Psychophysical measure of exertion. Following data collection during job performance workers were asked; "whether during the cycle there were job actions that required muscular effort of the upper limbs?" Workers consistently identified the turning task as primary and the positioning boards as a secondary sub task. Workers were then asked to rate the exertion required to turn and position boards on a scale of one to ten using the Borg CR-10 scale (Borg 1982). Workers were also asked to rate the strength demand required to turn the boards and the overall job demand on a 10 cm. visual analog scale (VAS) (Huskisson 1983).

7.2.6 Data Analysis

7.2.6.1 Comparisons and associations

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Mann-Whitney U test (alpha level 0.05) was used to determine if significant differences existed between facilities on the exposure variables recorded (range of motion, %MVC, Borg scores, VAS scores, body part discomfort ratings). The Friedman test (alpha level of .05) was used to test whether significant differences existed between posture variable definitions (peak, repetition average, overall average). Associations between exertion variables (%MVC, Borg, VAS) were tested with the Spearman's rho rank correlation test (alpha level 0.05). Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

7.2.6.2. Motion

7.2.6.2.1 Posture. Postures required to perform the board edger operator position were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed during the job sample and may not have taken place during a repetition of the primary task (turning boards). The repetition average (rep. avg.) posture was defined by randomly selecting 10 repetitions of the primary task (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average (OA) posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample.

7.2.6.2.2 Duty cycle. The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

7.2.6.2.3 Frequency. Repetitions of the primary task performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees in the pronation/supination plane. Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used. A change in direction of 18 degrees was selected by inspecting both the electrogoniometer output and simultaneous video of the job being performed and subjectively selecting the cut-point which differentiated between cycles of the primary task. Every time a motion exceeded the threshold value it was counted. The sum of these numbers over the sample time provided the frequency variable.

7.2.6.2.4 Velocity and acceleration. Motion information from 3 subjects randomly selected from each facility was used to derive velocity and acceleration variables. The angular excursion and time of motion was recorded for 5 samples of the supination/pronation excursion taken to be representative of flipping a board was assessed and used to calculate average velocity and acceleration values. Average velocity and acceleration were calculated by this method to enable the inertial component of the force necessary to perform the primary task to be calculated. Average values and not peak values were of interest as a "typical value" accounting for the variation in board dimension typically present was desired. Only ½ of the cycle was considered as it was assumed after the board reached the mid point gravity would be responsible for the remainder of the force required to complete the "flip". Single and double differentiating the displacement vs. time was used to calculate velocity and acceleration respectively.

7.2.6.3. Exertion

7.2.6.3.1 Electromyography. The EMG traces obtained during job simulated and maximum trials were full-wave rectified, averaged, and linear envelope-detected from the raw EMG signals. From those processed traces, peak EMG and average EMG was measured using custom software developed by the Ergonomics Research Laboratory at the University of Alberta. A sample of approximately 2 seconds of consistent activity from the 5 second trial was selected by reviewing the processed EMG signal of the primary agonist assessed according to the motion assessed (flexion – FCR, pronation PT). The job simulated flexion and pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the flexion and pronation components of the board turn task. An average % MVC value for the board turn task was then derived by averaging the flexion and pronation sub component MVC scores.

7.2.6.3.2 Dynamic force applied. Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration as described above.

7.3 Results

7.3.1 Incidence of upper extremity musculoskeletal injury

Alberta Workers Compensation Board data indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the board edger operator position. Calculation of incidence rates across the sawmill industry of Alberta Canada is not possible as no agency collects information of sufficient resolution on the entire workforce. Incidence rates calculated based on person year estimates, specific to the board edger operator, from the two facilities averaged 0.22 (facility A) and 1.33 (facility B) recorded musculoskeletal upper extremity incidents per person year in the period examined.

7.3.2 Subject characteristics

The average age of subjects was 33 (S.D. 6.3), average height of subjects was 178 cm (S.D. 6.1 cm), and average weight of subjects was 88.7 kg. (S.D. 13.4 kg.). Average work experience at the board edger position at time of assessment was 3.3 years (S.D. 2.1 yrs.).

7.3.3 Body part discomfort ratings

No significant differences in body part discomfort ratings were found specific to any body region between facilities. Discomfort reported by body region is presented in table 7-1. Percentage of the study population reporting discomfort (greater than 0 on a scale of 0-10) by body region is illustrated for the reader in figure 7-3.

7.3.4 Motion required

7.3.4.1 Posture/range of motion

Peak, repetition average, and overall average range of motion endpoints recorded are listed in table 7-2. Total range of motion by plane of motion are described in table 7-

3. Significant differences (p<.01) existed between facilities in total wrist excursion in the plane of wrist radial and ulnar deviation when repetition average endpoints were used only. Observed differences between facilities in mean repetition average radial and ulnar deviation angles were 9 degrees and 8 degrees respectively. No significant differences in total range of motion were observed between facilities in the planes of flexion/extension or pronation/supination when either the repetition average or peak endpoints were used. Given no significant differences between facilities assessed were found in the majority of between facility comparisons all subjects were then grouped to enable comparison of posture variable definitions. Total range of motion in all planes of motion were significantly different (p<.001) when repetition average were substituted for peak excursions to define the end points of the total range of motion. Reduction in total range of motion of 56%, 52% and 62% in the planes of radial/ulnar deviation, flexion/extension and supination/pronation respectively were recorded when repetition average postures and not peak postures were used to define end points. Our findings indicate the posture variable definitions examined were not equivalent.

7.3.4.2 Frequency of movements (board turning)

Descriptions of the observed frequencies of movement by facility examined are provided in table 7-4. Significant differences between facilities existed (p<.001) in all frequency variables examined. Observed differences between facilities in mean duty cycle, repetitions per minute (reps/min), hours per day (hrs/day), repetitions per day (reps/day) and total exposure were: 12%, 11.4 reps/min, 4 hrs./day, 7,349 reps/day and 1.27 hrs. respectively. An average of 80 cycles of the primary task were recorded in each subject.

7.3.4.3 Average velocity and acceleration (board turning)

No significant differences existed between the facilities examined in either the average velocity or acceleration employed to turn the boards. Derivation and resultant average velocity and acceleration values are reported in table 7-5.

7.3.5 Exertion required

An average of 33% of MVC (S.D. 8%) was required to turn a representative board. No significant differences were observed in the percentage of MVC required to perform the job between facilities ($p < .05$). Despite clarification of the instructions subject five scored the exertion required as "extremely strong" (level 10). As subject five is clearly an outlier, psychophysical measures of exertion scores are omitted from reported averages and tests of association. Workers assessed rated the effort required to turn boards an average of 5.1 (S.D.1.3) on the Borg CR-10 scale. No significant difference in workers %MVC required or psychophysical ratings of exertion required were found between facilities assessed. No significant correlation was observed between %MVC required and any psychophysical measure of exertion. No correlations were also found when the muscle demonstrating the highest %MVC, the flexion component muscle demonstrating the highest %MVC, or the pronation component muscle demonstrating the highest %MVC was compared to psychophysical measures. Borg average scores and Borg scores specific to positioning were significantly correlated to the VAS strength demand values. Co-efficient of determination (r^2) and level of significance of the correlations tested were found to be $r^2 = .53$ $p<.001$ and $r^2=.41$ $p<.02$ respectively. Muscle activity specific to muscle assessed is presented for the reader in table 7-6. Exertion scores (%MVC and psychophysical ratings) are presented for the reader in table 7-7.

7.4 Discussion

7.4.1 Measurement error

Initial calibration of the electrogoniometers used in this study on uni-planar calibration jigs revealed maximum angular differences between electrogoniometer and actual angle of 2.33, 3.67, and 3.33 degrees in the X, Y, and Z planes respectively. The results of our calibration studies were similar to those previously reported by Shiratsu and Coury (2003). Quantification of the error due to cross talk in multi-planar motions was not performed as a calibrated jig capable of quantifying degrees of motion in 3 dimensions simultaneously was not available. Cross talk during motion in multiple planes appears to have affected electrogoniometer output in the plane of radial and ulnar deviation in this study. In some cases recorded peak values recorded have fallen outside of accepted normal physiologic ranges (Magee 1997). Error in position measurement in the planes of flexion/extension and radial/ulnar deviation has been observed to be related to position in the supination/pronation plane of motion (Buchholz and Wellman 1997, Johnson et al. 2002). The magnitude of the error in the flexion/extension and radial/ulnar plane is related to the magnitude of supination/pronation and the wrist position used as the reference (zero) position (Johnson et al. 2002). In this experiment a mid-position of supination/pronation (which reflects the mid-position attained in performance of the task assessed) is used to reduce error due to the reference position migrating with deviation in the pronation/supination plane.

While the assessment of motion took place during actual job performance assessment of exertion required was based on a static assessment of a job simulated activity. While the validity of using the results of static EMG testing to indicate the demand of a dynamic activity is questionable, the requirement that the assessment be normalized to the subject and reliably performed across subjects necessitates the use of a static assessment. Normalized values are required to enable the calculation of risk assessment methodologies and the comparison of muscle activity across subjects. A static assessment was selected for the below reasons;

- Relative position: The position of the electrode relative to the muscle in a dynamic activity will change as the skin moves over the muscles of the forearm. For this reason muscle activity measured during a dynamic activity cannot be assumed to originate primarily from the agonist muscle of interest in a dynamic assessment. The normalization procedure also affects the validity of a dynamic assessment. The primary board turning task of interest is not performed in standardized postures. The validity of a dynamic procedure which imposes standardized positions in an effort to increase reliability is therefore limited for the same reasons as the static assessment.
- Velocity-tension relationship: If it was possible to maintain the relative position of the electrode to the agonist muscle during a dynamic activity the relationship of muscle activity to velocity of the motion remains unaccounted for. The muscle activity required to generate a given tension varies according to the velocity at

which the activity is performed. As the velocity required to perform the primary task is variable, selection of a normalization procedure which accounts for a single, or multiple velocities would be of questionable validity.

- Length-tension relationship: The relationship between muscle activity and tension varies according to the length of the muscle. As the activity requires no consistent muscle length, normalizing the MVC assessment to a group of muscle lengths would again be an assumption affecting the validity of the assessment similar to the static assessment.

7.4.2 Measured physical demands

Multiple authors have found that regardless of the assessors ergonomic experience worksite exposure measurement based solely on observation is prone to meaningful measurement error (Ketola et al. 2001, Spielholz 2001, Lowe 2004, Bao 2006). The compound effect of measurement error due to observation on multiple variables suggests that future examinations of observational ergonomic risk assessments be based on quantified exposure information. The comparison of the exposure variables reported here has demonstrated significant differences exist between definitions available to worksite evaluators using observation based measurements.

Posture variable definitions examined were shown to be significantly different dependent upon endpoints selected. Future studies examining the predictive validity of ergonomic risk assessments should therefore consider the effect of posture variable definitions on model output. No significant correlation was found between %MVC and any psychophysical measure of exertion. The lack of association between %MVC and psychophysical measures makes the examination of the effect of substituting exertion variables necessary in those models which allow multiple exertion variables to be used (Moore and Garg 1995, Occhipinti 1998). Significant differences between facilities were found in all measures of frequency. Significantly greater repetitions per minute and hours worked per day were found in facility A resulting in a total exposure 4.98 times greater on average than facility B. Interestingly, average annual incidence of recordable upper extremity musculoskeletal events in facility A was 6.05 times higher than in facility B. This finding seems to suggest that total exposure may be related to incidence of musculoskeletal events. Our ability to further examine this association is limited however, given the measures of incidence are not based on standardized criteria and thus may only offer a rough indication of the true incidence rates. The importance of this finding is further brought into question by the finding of no significant differences between facilities assessed in reported discomfort in any body region assessed.

In assessing the statistical significance of differences between facilities assessed the sample size considered is an important limitation of this study. The small samples compared (6 and 8 subjects) make the evaluation of assumptions upon which parametric statistics are based difficult and thus require use of non-parametric procedures. The power of the tests to detect differences and examine associations is therefore reduced. The sample obtained does represent the population of workers performing the board edger position at the time of assessment however.

7.5 Conclusion

In light of the foregoing discussion of the physical exposures recorded the following general picture of the data obtained in the study can be drawn: The collection of quantified physical exposure information has allowed the significant differences and/or lack of association between posture and exertion variables used in observational exposure assessments to be described. Differences between posture definitions and the lack of association between measures of exertion illustrate the importance of considering the effect of multiple variable definitions on ergonomic risk assessment output.

Occupational health records suggest that total exposure to the job may be related to the incidence of reportable upper extremity musculoskeletal events. Further examination of the association between differences in physical exposures and incidence of UEMSI is not possible given the limitations of the surveillance systems in use. Additional studies of the relationship between total exposure and incidence of UEMSI are needed based upon a standardized surveillance system. Such a system is not currently available in the sawmill industry of Alberta, Canada.

7.6 Acknowledgement

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Table 7-1: Reported discomfort by body region

Subject	Facility	Neck	Shld.	Upper arm	Forearm	Wrist	Upper L spine	Lower L spine	Mid back	Pelvis
1	a	5	2	0	3	0	0	5	0	0
2	a	0	7	0	0	5	0	5	0	0
3	a	7	5	0	5	5	0	0	0	0
4	a	0	2	0	2	0	2	0	0	0
5	a	1	5	2	0	0	5	6	0	0
6	a	5	0	7	0	7	0	0	7	0
7	b	2	2	0	0	0	0	3	0	0
8	b	2	1	1	1	4	1	1	1	1
9	b	0	0	0	0	0	0	0	0	0
10	b	2	5	2	0	0	5	5	0	0
11	b	0	0	0	0	0	0	0	7	0
12	b	0	6	0	0	3	0	0	0	0
13	b	0	5	0	5	0	0	0	0	0
14	b	0	3	0	0	0	0	0	3	0
	Avg.	2	3	1	1	2	1	2	1	0
	SD	2	2	2	2	3	2	2	3	0
	Min	0	0	0	0	0	0	0	0	0
	Max	7	7	7	5	7	5	6	7	1

Table 7-2: End range of motion values by posture variable definition in degrees

		Radial deviation		Ulnar deviation			Flexion		Extension			Pronation		Supination		
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**
1	**a**	17	5	47	33	15	42	22	74	28	0	43	29	41	31	5
2	**a**	13	7	35	26	10	28	19	32	24	4	37	29	25	16	6
3	**a**	10	3	43	30	10	49	12	52	39	7	30	22	35	23	0
4	**a**	0	-6**	50	44	23	30	20	64	44	13	43	31	30	21	6
5	**a**	17	6	52	37	17	81	42	41	26	-4*	33	20	41	32	-2*
6	**a**	20	6	45	33	10	53	8	74	53	12	52	37	35	12	4
7	**b**	34	12	35	22	5	60	28	62	36	3	46	36	57	33	5
8	**b**	21	2	38	26	11	43	3	68	46	21	8	-4	71	49	-29*
9	**b**	24	2	35	22	11	65	27	37	12	-6*	58	34	35	20	6
10	**b**	16	1	44	32	14	47	13	60	39	11	51	40	59	21	14
11	**b**	15	0	41	29	16	40	10	59	35	14	31	23	48	21	2
12	**b**	19	2	40	29	16	34	11	56	35	14	34	23	33	22	2
13	**b**	25	7	38	23	8	36	24	29	18	-2*	65	46	54	9	17
14	**b**	20	5	37	27	12	44	11	74	42	14	46	27	35	17	7
	Avg.	17.9	3.7	41.4	29.5	12.7	46.6	17.5	55.9	34.0	7.1	41.2	28.1	42.8	23.2	3.0
	SD	7.8	4.1	5.6	6.1	4.5	14.5	10.2	15.6	11.3	8.1	14.1	12.0	13.1	10.1	10.3
	Min	0	-6	52	44	23	28	3	74	53	21	8	-4	71	49	-29
	Max	34	12	35	22	5	81	42	29	12	-6	65	46	25	9	17

Rep avg.- Repetition Average, OA- Overall Average

* Indicates overall average values in ulnar deviation, extension, and supination plane of motion.

** Indicates joint end range value remains in ulnar deviation plane of motion

Table 7-3: Total range of motion values by end range posture variable definition in degrees

		Radial /Ulnar deviation		Flexion / Extension		Pronation / Supination	
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**
1	a	64	39	116	50	84	60
2	a	48	33	60	43	62	45
3	a	53	33	101	51	65	45
4	a	50	38	94	63	73	52
5	a	69	43	122	68	74	52
6	a	65	39	127	60	87	49
7	b	69	34	122	63	103	69
8	b	59	29	111	49	79	45
9	b	59	25	102	39	93	54
10	b	60	33	107	52	110	61
11	b	56	29	99	45	79	44
12	b	59	31	90	46	67	45
13	b	63	29	65	41	119	56
14	b	57	32	118	52	81	44
	Avg.	59.4	33.2	102.4	51.5	84.0	51.4
	SD	6.4	5.0	20.3	9.0	17.0	7.6
	Min	48	25	60	39	62	44
	Max	69	43	127	68	119	69

Table 7-4: Frequency variables recorded

Subject	Facility	Duty cycle	Reps/min	Hrs/day	Reps/day	Total exposure (Hrs.)
1	a	8%	8	2.97	1496	0.24
2	a	1%	1	3.33	208	0.03
3	a	12%	12	5.4	3970	0.63
4	a	10%	11	2.7	1779	0.28
5	a	11%	12	3.33	2398	0.38
6	a	10%	10	3.57	2242	0.35
7	b	20%	20	6.93	8268	1.40
8	b	24%	23	6.93	9622	1.63
9	b	23%	22	6.93	9338	1.58
10	b	13%	13	6.93	5377	0.91
11	b	25%	25	6.93	10259	1.74
12	b	14%	13	6.93	5594	0.95
13	b	28%	28	8.34	13965	2.34
14	b	21%	20	10.29	12497	2.16
	Avg.	16%	16	6	6215	1.04
	SD	8%	7	2	4437	0.76
	Min	1%	1	3	208	0.03
	Max	28%	28	10	13965	2.34

Table 7-5: Average velocity and acceleration; derivation and values

		Repetition 1		Repetition 2		Repetition 3		Repetition 4		Repetition 5		Avg. Velocity	Avg. Accel.
Subject	**Facility**	**Displacement (deg)**	**Time (sec)**	**Displacement**	**Time**	**Displacement**	**Time**	**Displacement**	**Time**	**Displacement**	**Time**	**deg/sec**	**deg/sec^2**
1	a	53	0.36	63	0.47	74	0.4	64	0.4	75	0.43	160.14	388.68
2	a	56	0.65	36	0.4	52	0.41	64	0.51	44	0.61	100.12	194.03
3	a	38	0.81	44	0.29	57	1.03	43	0.41	43	0.27	103.62	184.38
7	b	43	0.46	47	0.38	32	0.28	40	0.69	31	0.25	102.68	249.23
8	b	40	0.37	40	0.8	43	0.47	42	0.47	36	0.64	79.04	143.71
9	b	37	0.39	54	0.44	38	0.44	44	0.41	54	0.47	105.23	244.73

Table 7-6: Maximum and job simulated muscle activity by muscle assessed and task component

		% MVC				Component values	Task average	
Subject	**Facility**	**FCR**	**FCU**	**FDS**	**PT**	**Flex**	**Pronation**	**Overall average**
1	a	33%	22%	5%	88%	20%	88%	54%
2	a	58%	33%	11%	53%	34%	53%	43%
3	a	19%	19%	14%	44%	17%	44%	31%
4	a	39%	26%	18%	44%	28%	44%	36%
5	a	27%	23%	19%	34%	23%	34%	29%
6	a	37%	16%	16%	39%	23%	39%	31%
7	b	54%	73%	23%	10%	50%	10%	30%
8	b	32%	11%	15%	12%	19%	12%	16%
9	b	23%	32%	25%	33%	27%	33%	30%
10	b	33%	39%	33%	42%	35%	42%	38%
11	b	22%	10%	10%	50%	14%	50%	32%
12	b	28%	19%	47%	28%	31%	28%	29%
13	b	28%	20%	11%	42%	20%	42%	31%
14	b	22%	12%	8%	54%	14%	54%	34%
	Avg.	33%	25%	18%	41%	25%	41%	33%
	SD	11%	16%	11%	19%	10%	19%	9%
	Min	19%	10%	5%	10%	14%	10%	16%
	Max	58%	73%	47%	88%	50%	88%	54%

FCR – Flexor Carpi Radialis, FCU – Flexor Carpi Ulnaris, FDS- Flexor Digitorum Superficialis, PT- Pronator Teres

Table 7-7: Measures of exertion

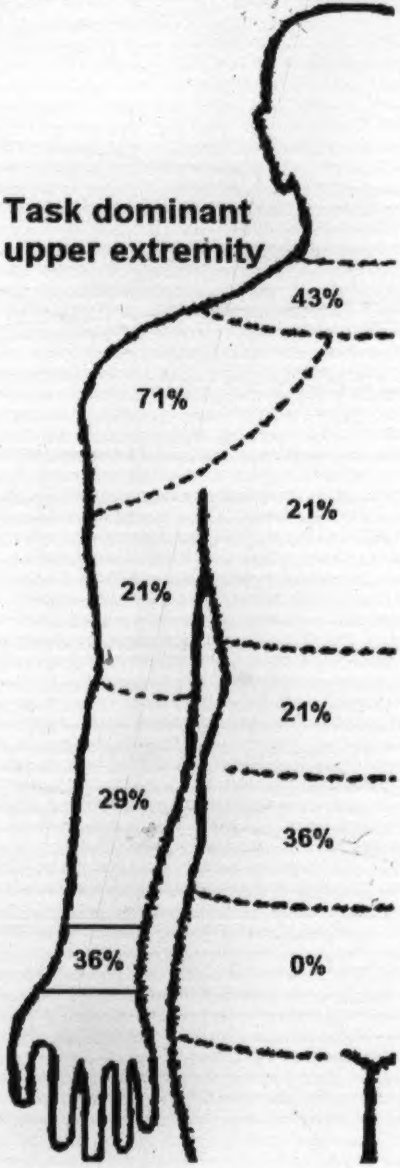
		Electromyography		Psychophysical measures				
Subject	**Facility**	**Dynamic Force (N.)**	**% MVC**	**Borg avg.**	**Borg turn**	**Borg position**	**VAS str. demand**	**VAS overall demand**
1	**a**	94.5	53%	5.5	5	6	7.3	6.4
2	**a**	94.5	43%	4	5	3	3.1	3.2
3	**a**	94.5	31%	5.5	4	7	5.5	5.5
4	**a**	94.5	36%	6	5	7	8.4	5.2
5	**a**	94.5	29%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6	**a**	94.5	29%	6	5	7	5	2
7	**b**	97.9	30%	4	4	4	4.5	6
8	**b**	97.9	15%	6	6	6	7.5	7.9
9	**b**	97.9	31%	4	5	3	4.2	2.9
10	**b**	97.9	39%	7	7	7	5.4	4.9
11	**b**	97.9	31%	6	7	5	6.3	7.5
12	**b**	97.9	29%	5	6	4	6.1	5.8
13	**b**	97.9	30%	4.5	5	4	5	5.2
14	**b**	97.9	33%	3	2	4	3.5	4.2
	Avg.	96.4	33%	5.1	5.1	5.2	5.5	5.1
	SD	1.7	8%	1.1	1.3	1.6	1.6	1.7
	Min	95	15%	3	2	3	3	2
	Max	98	53%	7	7	7	8	8

* Psychophysical scores of subject 5 not included in descriptive statistics reported

Figure 7-1: Board edger operator

Figure 7-2: Job simulated exertion set-up

Figure 7-3: Percentage of subjects reporting discomfort



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Chapter 8 – Assessment of physical exposures and comparison of exposure definitions in a repetitive sawmill occupation: lumber grader

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8.1 Introduction

Musculoskeletal injuries in the upper extremity accounted for 1698 Workers Compensation Board claims in the sawmill industry of Alberta, Canada from 1997-2002 (Jones and Kumar, 2004). Musculoskeletal injuries accounted for 33% of the total cost of claims and 38% of the total time lost due to claim in the same period. Within the sawmill industry the lumber grader production position was identified as a production position with a high risk of upper extremity musculoskeletal injuries (MSI). Incidence of recordable upper extremity MSIs in the lumber grader position ranged from .09 to .25 per person year worked in the facilities examined.

Given the large human and financial burden imposed on industry by MSIs prevention efforts have become a priority of occupational health programs. A large evidence base establishing the role of physical exposures in precipitation of MSIs is now present and a number of probable mechanisms of injury have been proposed (U.S. Department of Health and Human Services, 1997; Kumar, 2001). Given this evidence prevention efforts which seek to reduce the occurrence of MSI through the control of physical exposures are justified. In most musculoskeletal conditions it is the combined effect of physical exposures which are most highly related to incidence of MSI (US Dept. Health and Human Services, 1997). Ergonomic risk assessments are based on models of MSI causation which consider the combined role of physical exposures related to MSI. Because of their ability to account for the role of combined exposures in MSI causation ergonomic risk assessments are used in industrial prevention efforts to identify at-risk jobs and problem exposures for intervention (Moore and Garg, 1995; Occhipinti, 1998). Calculation of an ergonomic risk assessment first requires the evaluator define the physical exposures required to perform the job. Traditionally, worksite exposure assessments have been performed based on observation. Multiple definitions of the posture and exertion variable are available to worksite evaluators performing an observation based exposure assessment. Based on observation the evaluator may define posture according to multiple definitions, three such definitions are: the peak posture observed in the plane of interest during any point in the job sample, the peak posture observed considering only the primary task performed, or the overall average posture considering all motions in the job sample. Similar to posture the exertion variable may be defined in a number of ways. Depending upon the risk assessment used exertion required may be defined using either quantitative measures such as surface electromyography (percentage of maximum voluntary contraction) or psychophysical measures (e.g. Borg Cr-10 scale) (Borg, 1982; Moore and Garg, 1995; Occhipinti, 1998). Studies examining the equivalency of the multiple definitions are necessary as it is reasonable to assume posture and exertion variable definition will impact the validity of ergonomic risk assessments performed based on these variables. Only a recent study by Jones and Kumar (2006) has sought to describe the equivalency of the multiple definitions of posture and exertion.

Valid comparison of exposure variable definitions requires as accurate a measure of exposure as possible. Literature is now present which describes the meaningful measurement error resulting from exposure measurement via observation. Lowe (2004) examined the ability of worksite evaluators to correctly classify forearm and wrist posture and found rates of misclassification ranged from 22% to 70% when compared to measurements made by electrogoniometers (Lowe, 2004). Bao et al. (2006) found limited correlations between frequency classifications made by ergonomists based on observation and measurements based on detailed time studies (Bao et al., 2006). Due to the meaningful measurement error resulting form exposure assessment via observation electrogoniometers and surface electromyography were used in this study to assess the physical exposures required to perform the lumber grader job.

It is the intent of this paper to describe the physical exposures required to perform a high risk sawmill job by multiple definitions of posture, exertion and frequency and examine the comparability of those definitions. The definitions of the exposure variables examined have been chosen to reflect those available to worksite evaluators performing observation based assessments. The definitions used also reflect those required to apply ergonomic risk assessment techniques. Differences in exposures between facilities were examined in an effort to explain meaningful differences in recorded incidence rates between facilities. The comparability of ergonomic risk assessment techniques, calculated based on quantified exposures, and the effect of altering variable definition will be examined in a subsequent paper.

8.2. Methods

8.2.1 Occupation identification

Deriving incidence rates specific to the lumber grader position using compensation information is not possible given information describing the complete work force is not available (Jones and Kumar, 2004). For this reason the occupational health records of the three sawmill facilities participating were consulted to determine which production positions were commonly associated with injuries of a musculoskeletal nature to the upper extremity and the lumber grader position was selected.

8.2.2 Task description

The lumber grader is responsible for assigning a product grade to each piece of dimensional lumber leaving a sawmill. Board dimensions to be graded vary from 243.8 cm. to 609.6 cm. in length, 10.2 – 25.4 cm. in width, and 5.1 – 10.2 cm. in thickness. In order to assign the grade to a piece of dimensional lumber the lumber grader must inspect the four sides of board. Inspecting all surfaces requires the board to be turned with the task dominant upper extremity. When a grade has been chosen the lumber grader places a mark with a reflective marker on the piece of dimensional lumber, to enable automated sorting, with the remaining upper extremity. Boards were observed to vary in weight from 2.27 – 22.7 kg. dependent upon dimension, species of wood and moisture content. Figure 8-1 depicts the primary board turning task of the lumber grader.

8.2.3 Subject selection

Male and female workers presently performing the lumber grader position ages 18-65 were recruited at the three sawmill facilities studied. Subjects were excluded from the study if they reported: injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. No female workers were present at the three facilities examined. 29 of 30 male subjects gave their informed consent and volunteered to take part in the study (97% participation).

8.2.4 Body part discomfort survey (Corlett and Bihop, 1976)

Each worker was asked to complete a body part discomfort rating survey prior to beginning data collection. Ratings ranged from 1 (indicating no discomfort) to 10 indicating the body region was "very uncomfortable". Ratings greater than 1 were taken to indicate discomfort.

8.2.5 Data collection

8.2.5.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to turn boards during job performance. Only the upper extremity used to turn boards (task dominant upper extremity) was assessed. A Biometrics bi-axial SG-65 and uni-axial Q-150 electrogoniometer were applied to the task dominant upper extremity as per the users' manual recommendations (Biometrics, 2002). Prior to beginning data collection the subjects were asked to position their elbow at 90 degrees, their forearm in mid position (thumb positioned superiorly), and wrist in neutral position in the planes of flexion/extension and radial/ulnar deviation while the electrogoniometers were zeroed. A sample of 5 minutes was recorded during job performance. Angular displacement was recorded in 3 planes (X,Y,Z) with a bi-axial and uni-axial Biometrics ™ electrogoniometer at 200 Hz. Postures and frequencies required to perform the job were determined through analysis of the recorded wave forms with the Biometrics Data link analysis software.

8.2.5.2 Exertion data acquisition

Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction and job simulated exertions in static trials. Job simulated and maximum EMG trails were performed at a location removed from the production line. Only the upper extremity reported by the subjects as primarily used to turn boards (task dominant upper extremity) was assessed. The flexor carpi radialis, flexor carpi ulnaris, and flexor digitorum superficialis were assessed for the flexion component and the pronator teres was evaluated for the pronation component of the board flip task. Electrode placement was determined by isolating the muscle in question with manual muscle testing performed by a physical therapist and placing the electrode in approximately the midpoint of the muscle belly. A Delsys Bagnoli 8 EMG system was used to record the muscle activity of all muscles assessed in each trial. Single differential bi polar electrodes with parallel bar shaped silver detection surfaces (1 cm. length x 1 mm. width) spaced 1 cm. apart were used in the EMG trials and oriented perpendicular to the muscle fibers. The data acquisition system consisted of an analog-to-digital board with a 100-kHz sampling capacity. The EMG channels (4) were sampled at 1 kHz in real time. The sampled signals were stored on a laptop computer. The EMG traces obtained during job simulated and maximum trials were full-wave rectified and linear envelope-detected from the raw EMG signals. From those processed traces, peak EMG and average EMG was measured using custom software developed by the Ergonomics Research Laboratory at the University of Alberta. Data acquisition took place during a 9 second sample to cover the entire task cycle. 2 seconds prior to the assessors instructions to begin were used to record a baseline activity and 2 seconds following the 5 second test were used to allow the subject to return to baseline values. Experimental trials were administered in random order to allow differences observed to be attributed to differences in the experimental conditions and not the order of trials. A minimum of 2 minutes rest was given to subjects between trials to prevent fatigue. Two trials were performed for each condition with the second trial being recorded to allow the subject to become familiar with the task.

8.2.5.2.1. Maximum voluntary contraction trial: During the MVC trials the subject was seated with the task dominant upper extremity positioned at the side and the elbow bent to 90 degrees. An isometric exertion in either a flexion or rotational direction on a handle made from a piece of dimensional lumber connected to an immobile base by a steel cable was performed dependent upon the trial (wrist flexion or pronation). During flexion trials the steel cable was connected to the middle of the handle and the subject was instructed to perform a static flexion exertion. During the pronation trail an alternate handle to which the steel cable was attached to the outside edge was used and the subject was instructed to exert a static rotational exertion on the handle. During MVC trials the subject was instructed as follows: "When I say go, I want you to bring your force up to your (maximum level) over 2 seconds and hold for 3 seconds or until I say stop."

8.2.5.2.2 Job simulated trial: Job simulated trials were performed in a location removed from the industrial process (e.g. coffee room) within the facility. Job simulated muscle activity was determined by having the subject maintain a representative board (5.1 cm. deep by 20.3 cm. wide, 488 cm. long) in a job simulated standardized static position while muscle activity was recorded. This dimension was selected as representative because it was produced in all facilities examined and shifts in which this dimension is graded were reported by the majority of subjects to be the most demanding. Subjects were tested in standing with the wrist in neutral flexion/extension and supinated position (job simulated flexion) or slightly pronated from full supination position (job simulated pronation). The height of the mock up table was adjusted such that the subject maintained the board at an angle of approximately 3 degrees from the horizontal plane of the mock up table at 90 degrees of elbow flexion. In job simulated trials the weight of the representative board was supported by the assessor until the trial was begun. After the trial was begun the weight of the representative board was given to the subject and maintained for approximately 5 seconds until removed by the assessor.

8.2.5.2.3 Psychophysical measure of exertion: Following motion data collection workers were asked; "whether during the cycle there were job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the exertion required to perform the actions from one to ten using the Borg CR-10 scale (Borg 1982). Workers were also asked to rate the strength demand required to turn the boards and the overall job demand on a 10 cm. visual analog scale (Huskinsson, 1983).

8.2.6 Data Analysis:

8.2.6.1 Comparisons

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Kruskal Wallis H test (alpha level 0.05) was used to determine if significant differences existed between facilities on the exposure variables recorded (range of motion, %MVC, Borg scores, VAS scores, body part discomfort ratings). The Friedman test (alpha level of .05) was used to test whether significant differences existed between posture variable definitions (peak, repetition average, overall average). Associations between exertion variables (%MVC, Borg, VAS) were tested with the Spearman's rho rank correlation test (alpha level 0.05). Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

8.2.6.2 Motion

8.2.6.2.1 Posture: Postures required to perform the lumber grader position were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (turning boards). The repetition average posture was defined by randomly selecting 10 repetitions (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally the overall average excursion was calculated considering all motions in the plane of interest for the entire sample. Overall average posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample.

8.2.6.2.2 Duty cycle: The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

8.2.6.2.3 Frequency: Repetitions performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees at the proximal radio-ulnar joint (pronation/supination). Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used. A change in direction of 18 degrees was selected by inspecting both the electrogoniometer output and simultaneous video of the job being performed and subjectively selecting the cut-point which differentiated between cycles of the primary task. Every time a motion exceeded the threshold value it was counted. The sum of these numbers over the sample time provided the frequency variable.

8.2.6.2.4 Velocity and acceleration: The angular excursion and time of motion was recorded for 5 samples of the supination pronation excursion taken to be representative of flipping a board for 3 subjects at each facility assessed and used to calculate average velocity and acceleration values. Only ½ of the cycle was considered as it is assumed after the board reached the mid point gravity would be responsible for the remainder of the force required to complete the “flip”. Angular excursion was divided by the time necessary to reach the midpoint of the cycle to arrive at the average velocity. Single and double differentiating the displacement vs. time was used to calculate velocity and acceleration respectively.

8.2.6.3. Exertion

8.2.6.3.1 Electromyography: Percentage of maximum voluntary contraction: A sample of approximately 2 seconds of consistent activity from the 5 second trial was selected by reviewing the processed EMG signal of the primary agonist assessed according to the motion assessed (flexor carpi radialis – flexion, pronator teres- pronation). The average value resulting from the muscles assessed during the job simulated flexion trial and the job simulated pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the flexion and pronation components of the task.

8.2.6.3.2 Dynamic force applied: Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration as described above.

8.3. Results

8.3.1 Incidence of upper extremity musculoskeletal injury

The Alberta Workers Compensation Board data set indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the lumber grader position. Insufficient resolution was present in the occupation title field of the WCB database to identify specific job titles. For this reason the occupational health records of the three facilities participating were reviewed (1997-2002). Incidence rates, specific to the lumber grader position, calculated based on person year estimates from the three facilities averaged 0.23 (facility A), 0.25 (facility B) and 0.09 (facility C) recordable upper extremity incidents of a musculoskeletal nature per person year in the period examined.

8.3.2 Subject characteristics

The average work experience at the lumber grader position at time of assessment was 4.4 years (S.D. 4.9 yrs.). Average age of the lumber graders assessed was significantly different across the facilities assessed. Maximum differences between the mean age of lumber graders was 9.8 years and mean ages between facilities ranged from 29.9 to 37.1 years. Average height of the lumber graders was also significantly different between facilities assessed. Maximum mean height difference was observed to be 9.5 cm. and mean heights ranged from 174.4 to 183.8 cm. Average weight of subjects did not differ between facilities assessed. Mean weight of the lumber graders assessed was 81.6 kg. (S.D. 14.7 kg.).

8.3.3 Body part discomfort survey scores

59 % of the subjects evaluated reported discomfort of greater than moderate discomfort (greater than 4 on a scale of 0 to 10) in the task dominant upper extremity. Reported discomfort by body region is described in table 8-1. No significant differences in reported discomfort in any region assessed were found between facilities. Percentage of the study population reporting discomfort (greater than 1 on a scale of 0-10) by body region is illustrated for the reader in figure 8-2.

8.3.4 Motion required

8.3.4.1 Posture/joint excursion

Peak, repetition average, and overall average ranges of motion observed in the recorded sample are listed in table 8-2 by plane of motion. Significant differences between facilities were recorded in peak and repetition average supination end points ($p<.05$) and peak wrist extension ($p<.05$). Maximum mean angular differences between facilities with respect to the measures of forearm supination were 9.8 degrees (peak) and 8.7 degrees (repetition average) respectively. Maximum mean angular differences between facilities in peak extension were 18.4 degrees. When total range of motion values specific to each plane of motion (e.g., wrist radial/ulnar deviation) were compared only wrist flexion/extension, when endpoints were defined by the peak postures observed, were significantly different between facilities assessed ($p<.01$). Maximum mean angular difference between facilities in total peak flexion/extension range of motion was 25.5 degrees. Total joint excursions defined by peak posture endpoints were significantly different ($p<.001$) than total joint excursions defined by repetition average endpoints in every plane of motion examined. Total joint ranges of motion by end range definition are described for the reader in table 8-3.

8.3.4.2 Frequency of movements (board turning)

Descriptions of the observed frequencies of movement by facility examined are provided in table 8-4. Average repetitions performed per minute (34.2 reps/min) did not vary significantly between facilities. Hours spent performing the lumber grader position did vary significantly between facilities ($p<.01$). Maximum mean difference between facilities with respect to hours spent per day performing the lumber grader job was 3.7 hours per day and ranged from 3.5 (facility b) to 7.2 (facility c). Significant differences in hours spent per day resulted in significantly different total repetitions per day as well ($p<.001$). The maximum mean difference in total repetitions performed per day was 8,497.6 and ranged from 7,115.4 (facility b) to 15,613.1 (facility c). Finally, the percentage of the sample active (duty cycle) varied significantly between facilities assessed. Maximum mean difference in the percentage of the cycle active was 12% and duty cycles varied from 33% (facility b) to 45% (facility a). Average velocity and accelerations employed to turn the boards were 125.4 degrees/sec (S.D. 32.6) and 293.5 degrees/sec^2 (S.D. 102.8) respectively. No significant differences were found between facilities with respect to the average velocities or accelerations applied to turn boards. Derivation and resultant average velocity and acceleration values are reported in table 8-5.

8.3.5 Exertion required

An average of 11% of MVC (S.D. 5%) was required to turn a representative board (5.1 cm. deep by 10.2 cm. wide, 243.8 cm. long). Representative board weights upon which the job simulated MVC testing was performed varied from 3.2 to 3.9 kgs. No significant differences were observed between facilities with respect to the percentage of MVC required to perform the primary job task. Significant differences between facilities were observed ($p<.05$) in the Borg rating of exertion. The maximum mean difference in Borg score attributed to the turning of boards was 2.3 points and mean values ranged from 4.0 to 6.3. Increasing Borg scores were not associated with differences between facilities in any frequency or subject characteristic (worker age or height) measure. No association was found between % MVC and any psychophysical measure of exertion. Borg score was significantly related to both the VAS measure of strength demands and the VAS measure of overall demand however ($p<.001$, $r^2 = .47$ and $p<.001$, $r^2 = .44$ respectively). % MVC specific to muscle assessed is presented for the reader in table 8-6. Exertion scores (%MVC and psychophysical ratings) are presented for the reader in table 8-7.

8.4. Discussion

8.4.1 Quantified physical exposures

Numerous authors have studied the large error resulting from posture measurement by observation (Ketola et al., 2001; Lowe, 2004; Spielholz et al. 2001). Initial calibration of the electrogoniometers through measurement ranges available physiologically on uni-planar jigs revealed maximum errors of 2.33, 3.67, and 3.33 degrees in the planes of wrist radial/ulnar deviation, flexion/extension, and pronation/supination respectively. The results of our calibration studies were similar to those previously reported by Shiratsu and Coury (2003). Importantly, error due to motion in multiple planes of wrist motion simultaneously was not assessed in this study. Error due to multi-planar motion appears to have been important as peak wrist radial and ulnar deviation angles recorded in this study often approached and/or exceeded ranges reported to represent normal (Magee, 1997). Studies of the effect of measurement error due to multi-planar motion have reported mean errors of up to 6 ± 5 degrees in the electrogoniometers used in this study (Jonsson and Johnson, 2001).

8.4.2 Measured physical exposures

No significant differences were found between facilities in the majority of wrist and forearm range of motion variables. The lack of significant differences between facilities examined enabled the grouping of all subjects to allow the examination of the effect of the different posture variable definitions used. Posture variable definitions examined were shown to be significantly different dependent upon endpoints selected and therefore not equivalent. Future studies examining the predictive validity of ergonomic risk assessments which consider posture must therefore consider the effect of posture variable definitions on model output. No association was found between %MVC required to turn a representative board and any psychophysical measure of exertion. The lack of association between %MVC and psychophysical measures makes the examination of the effect of substitution necessary in those ergonomic risk assessment methods which allow either to be used (Moore and Garg, 1995; Occhipinti 1998).

8.4.3 Limitations

Measurement error in posture and motion assessment due to simultaneous multi-planer motion was not controlled in this study. Additionally, only five minutes of job performance was recorded with electrogoniometers and assumed to be representative of the task. The repetitive nature of the job assessed which allowed approximately 170 repetitions of the primary task to be assessed supports the representativeness of the sample used here in comparison to those taken by observation however. While motion and posture information was recorded during actual job performance static EMG assessment was used to assess the muscle activity required to perform a dynamic task. While the validity of using the results of a static assessment to represent the exertion required to perform a dynamic task is questionable, the requirement that the assessment be normalized and reliably performed across subjects necessitated the use of a static assessment. In assessing the significance of differences between facilities the sample size considered is an important limitation of this study. The small samples compared make the evaluation of the assumptions upon which parametric statistics are based unreliable and thus require the use of non-parametric procedures. The power of the tests to detect differences and examine associations is therefore reduced. The sample obtained does represent the population of workers performing the lumber grader position in the facilities participating at the time of assessment however. The resolution of the compensation data set and the incomparability of the surveillance systems of the three facilities participating are also important limitations of this study. While seemingly significant differences exist between facilities with respect to incidence rates our confidence in this finding as well as our ability to examine the relationship between differences in exposure recorded and differences in incidence is restricted by our ability to group the information. Additional studies of the relationship between individual and combined exposures and incidence of MSI are needed based upon a standardized surveillance system. Such a system is not currently available in the sawmill industry of Alberta, Canada.

8.5. Conclusion

Use of electromyography and electrogoniometry into worksite assessment has enabled the reliable measurement of physical exposures at a level of resolution not previously possible. Quantification of physical exposures has allowed us to demonstrate significant differences exist between commonly used posture variable definitions and a lack of association between exertion variables determined quantitatively and psychophysical measures. This finding suggests that future studies examining the predictive validity of ergonomic risk assessments causation should concurrently examine the effect of posture and exertion variable definition.

8.6 Acknowledgement

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Table 8-1: Reported discomfort by body region

Subject	Facility	Neck	Shld	Upper arm	Forearm	Wrist	Mid back	Upper L spine	Lower L spine	Pelvis
1	a	0	7	0	0	0	7	0	6	0
2	a	2	5	0	5	5	7	0	4	0
3	a	0	0	0	0	0	9	0	0	0
4	a	0	7	7	5	0	0	0	0	0
5	a	5	0	0	0	0	0	5	0	0
6	a	3	4	3	3	5	9	5	3	2
7	a	0	4	0	0	0	0	0	6	0
8	b	3	2	1	3	0	1	3	3	1
9	b	0	0	0	0	0	5	3	0	0
10	b	0	0	5	5	0	0	0	2	0
11	b	0	0	0	2	2	0	0	0	0
12	b	1	3	1	2	0	3	1	1	1
13	b	2	2	0	7	7	0	0	2	0
14	b	0	2	0	0	2	0	0	0	0
15	b	0	0	0	0	0	6	0	0	0
16	b	9	0	6	6	5	0	0	9	0
17	b	7	6	8	8	8	0	0	0	0
18	b	0	5	0	3	0	0	0	4	0
19	c	5	0	0	0	0	0	0	0	0
20	c	5	8	0	0	0	8	0	0	0
21	c	0	5	0	5	5	0	0	0	3
22	c	7	0	0	0	5	5	0	0	0
23	c	7	7	0	0	0	7	0	0	0
24	c	0	2	0	0	0	0	0	0	0
25	c	0	0	5	5	0	0	0	3	0
26	c	5	5	1	1	0	5	5	7	2
27	c	0	0	0	0	0	0	0	0	0
28	c	3	0	0	0	0	0	0	4	0
29	c	10	10	0	0	0	0	0	0	0
	Avg.	3	3	1	2	2	2	1	2	0
	S.D	3.13	3.05	2.42	2.58	2.53	3.36	1.66	2.57	0.76
	Min.	0	0	0	0	0	0	0	0	0
	Max.	10	10	8	8	8	9	5	9	3

Table 8-2: End range of motion values by posture variable definition in degrees

		Radial deviation		Ulnar deviation			Flexion		Extension			Pronation		Supination		
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**
1	a	23	14.3	-17	1.7	8.7	26	11.4	-41	-25	-7.1	49	42.5	-38	-28.1	2.1
2	a	16	12.9	-25	-16.1	-1.5	25	5.68	-35	-24.9	-9.2	48	43.5	-32	-20.2	9.7
3	a	11	4.54	-24	-13.3	-4.9	28	6.9	-58	-44	-14.5	46	33.9	-27	-19.5	-0.7
4	a	3	-7.2	-50	-41.4	-24.2	25	4.8	-58	-45.6	-21	62	55.5	-30	-19.3	18.5
5	a	8	1.53	-21	-9.8	-4.2	-2	-21.6	-55	-43.3	-30.5	54	43.5	-13	-5.71	18.4
6	a	21	13.9	-41	-12.7	1.4	18	4.3	-53	-46.2	-19.8	41	29.4	-19	-12.5	1.3
7	a	13	1.17	-35	-11.6	-5.1	28	9.4	-42	-31.9	-2.2	35	15.7	-32	-23.9	-7.8
8	b	11	5.4	-26	-10.2	-2.9	6	-4.6	-60	-46.5	-24.4	48	34.7	-32	-29.1	1.1
9	b	25	16	-21	-4.4	4.9	21	-6.3	-79	-57.3	-24.8	31	18.4	-52	-30.3	-13.1
10	b	1	-9.4	-35	-26.3	-17.2	50	-1.4	-58	-38.9	-17.8	30	24.4	-38	-20	6.6
11	b	5	-11.6	-36	-30	-18.9	48	15.5	-47	-23.6	0.5	37	24.6	-22	-9.6	8.6
12	b	1	-7.2	-40	-31	-19.9	32	6.8	-52	-30.3	-9.5	41	32.8	-32	-20.8	8.4
13	b	13	1	-38	-13.1	-5.1	23	2.81	-68	-49.2	-17.9	47	33.5	-32	-22.1	6
14	b	18	9.6	-37	-16.2	-3.31	20	2	-53	-37.6	-13	54	45.6	-35	-15.8	14.7
15	b	17	2.4	-44	-18.3	-6	31	-13.6	-106	-45.9	-26.3	57.7	39.3	-44	-23.6	7.3
16	b	6	-6.5	-38	-27.8	-16.4	24	-11.2	-73	-57.9	-31.5	46	16.8	-36	-21.7	-2.1
17	b	17	10.9	-26	-8.6	2.1	33	20.2	-72	-30.9	-2.5	44	37.2	-32	-27	6
18	b	5	-4.7	-35	-23.5	-14.5	23	-8	-72	-55.1	-25.3	53	37.2	-49	-37.1	-2.8
19	c	10	-10.3	-35	-27.4	-19.4	62	14.2	-39	-26.7	-1.3	31	20.3	-27	-10.4	3.2
20	c	9	-3.2	-50	-38.4	-17.3	41	15.5	-46	-26.8	-2	28	21.4	-35	-15.2	4.8
21	c	15	4.3	-38	-18	-6.5	55	-8	-49	-40.2	-23.4	73	62.8	-33	-18.3	24.2
22	c	13	5.4	-42	-22.1	-8.5	40	8.2	-55	-45.6	-18.9	60	52.1	-26	-6.6	23.8
23	c	10	7.1	-17	-10.2	0.2	10	-16.7	-68	-62.1	-33.3	34	20.9	-21	-16.8	2.9
24	c	11	-11.3	-43	-33.6	-19.9	12	-8.2	-89	-74.7	-46.5	33	19.4	-17	-10.7	9.5
25	c	27	14.3	-19	-7.05	1.5	6	-6	-67	-59.3	-22.8	43	38.3	-29	-19.5	8.8
26	c	7	2.7	-40	-21.2	-9.4	36	-1.3	-57	-41.4	-18.2	30	25.2	-19	-12.6	9.3
27	c	15	2.7	-39	-21.6	-7.9	26	13.2	-58	-53	-10.8	28	19.3	-34	-25.5	-4.5
28	c	19	14.6	-26	-3.4	5.3	23	8	-44	-20.4	-1	51	34.4	-16	-10.2	13.7
29	c	15	7	-38	-13	-2.9	28	-8	-79	-67.4	-29.2	37	26.2	-39	-15.7	4.2
	Avg.	13	3	-34	-18	-7	28	1	-60	-43	-17	44	33	-31	-19	6
	S.D	6.77	8.63	9.44	10.64	8.86	14.60	10.64	15.86	14.07	11.63	11.45	12.23	9.35	7.51	8.63
	Min.	1	-11.6	-50	-41.4	-24.2	-2	-21.6	-106	-74.7	-46.5	28	15.7	-52	-37.1	-13.1
	Max.	27	16	-17	1.7	8.7	62	20.2	-35	-20.4	0.5	73	62.8	-13	-5.71	24.2

Rep avg.- Repetition Average, OA- Overall Average

Negative values indicate end range of motion in ulnar deviation, extension, or supination.

* Indicates end range of motion did not cross the midpoint from radial deviation into ulnar deviation and remains in ulnar deviation.

** Indicates end range of motion did not cross the midpoint from flexion into extension and remains in extension.

Table 8-3: Total joint excursion values by end range posture variable definition in degrees

		Radial /Ulnar deviation		Flexion / Extension		Pronation / Supination	
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**
1	a	40	13	67	36	87	71
2	a	41	29	60	31	80	64
3	a	35	18	86	51	73	53
4	a	53	34	83	50	92	75
5	a	29	11	53	22	67	49
6	a	62	27	71	51	60	42
7	a	48	13	70	41	67	40
8	b	37	16	66	42	80	64
9	b	46	20	100	51	83	49
10	b	36	17	108	38	68	44
11	b	41	18	95	39	59	34
12	b	41	24	84	37	73	54
13	b	51	14	91	52	79	56
14	b	55	26	73	40	89	61
15	b	61	21	137	32	102	63
16	b	44	21	97	47	82	39
17	b	43	20	105	51	76	64
18	b	40	19	95	47	102	74
19	c	45	17	101	41	58	31
20	c	59	35	87	42	63	37
21	c	53	22	104	32	106	81
22	c	55	28	95	54	86	59
23	c	27	17	78	45	55	38
24	c	54	22	101	67	50	30
25	c	46	21	73	53	72	58
26	c	47	24	93	40	49	38
27	c	54	24	84	66	62	45
28	c	45	18	67	28	67	45
29	c	53	20	107	59	76	42
	Avg.	46	21	87	44	75	52
	S.D	8.92	5.84	17.96	10.62	15.08	14.08
	Min.	27	11	53	22	49	30
	Max.	62	35	137	67	106	81

Table 8-4: Frequency variables recorded

Subject	Facility	Duty cycle	Reps/min	Hrs/day	Reps/day	Total exposure (Hrs.)
1	a	56%	40	6.75	16241	3.79
2	a	51%	36	6.75	14712	3.43
3	a	36%	25	6.75	10300	2.40
4	a	41%	29	6.75	11808	2.76
5	a	44%	32	6.75	12760	2.98
6	a	46%	33	6.75	13193	3.08
7	a	40%	28	6.75	11535	2.69
8	b	39%	39	0.9	2129	0.35
9	b	18%	18	0.9	953	0.16
10	b	38%	38	4.5	10125	1.69
11	b	30%	30	4.5	8202	1.37
12	b	31%	31	4.5	8365	1.39
13	b	44%	44	3.51	9204	1.53
14	b	33%	33	3.51	6867	1.14
15	b	30%	30	4.5	8213	1.37
16	b	38%	38	4.5	10353	1.73
17	b	33%	33	3.51	7024	1.17
18	b	32%	32	3.51	6835	1.14
19	c	47%	46	7.26	19867	3.42
20	c	40%	38	8.12	18651	3.21
21	c	34%	33	6.82	13567	2.34
22	c	45%	44	7.26	19044	3.28
23	c	40%	38	5.42	12439	2.14
24	c	37%	35	4.12	8745	1.51
25	c	41%	40	7.26	17457	3.01
26	c	26%	25	9.75	14562	2.51
27	c	34%	33	8.12	15879	2.73
28	c	40%	39	7.26	16826	2.90
29	c	31%	30	8.12	14707	2.53
	Avg.	38%	34.2	5.7	11743.6	2.2
	S.D	8%	6.17	2.14	4754.05	0.96
	Min.	18%	18	0.9	953	0.16
	Max.	56%	46	9.75	19866.62	3.79

Table 8-5: Average displacement, duration, velocity and acceleration values used to perform board turning

	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Repetition 5			
Facility	**Displacement (deg)**	**Time (sec)**	**Displacement**	**Time**	**Displacement**	**Time**	**Displacement**	**Time**	**Displacement**	**Time**	**Avg. Velocity deg/sec**	**Avg. Accel. deg/sec^2**
a	68	0.3	74	0.42	79	0.37	73	0.47	75	0.49	184.95	451.10
a	47	0.49	48	0.43	49	0.43	57	0.56	61	0.64	103.72	203.37
a	52	0.43	50	0.41	56	0.45	56	0.65	54	0.47	113.67	235.84
b	64	0.67	53	0.36	75	0.5	61	0.44	70	0.58	130.41	255.71
b	49	0.47	58	0.41	48	0.36	50	0.34	50	0.44	127.95	316.71
b	34	0.34	44	0.48	42	0.41	39	0.39	64	0.39	111.64	277.72
c	26	0.34	25	0.4	33	0.26	32	0.19	35	0.19	123.71	448.21
c	79	0.66	82	0.62	79	0.33	85	0.51	71	0.49	160.58	307.63
c	34	0.61	36	0.53	35	0.49	34	0.46	33	0.37	71.64	145.61

Table 8-6: Percentage of maximum voluntary contraction by muscle assessed and task component

		% MVC				Component values		Task average
Subject	**Facility**	**FCR**	**FCU**	**FDS**	**PT**	**Flex**	**Pronation**	**Overall average**
1	a	10%	8%	5%	7%	8%	7%	7%
2	a	11%	6%	7%	9%	8%	9%	8%
3	a	5%	2%	3%	3%	3%	3%	3%
4	a	13%	8%	11%	7%	11%	7%	9%
5	a	10%	8%	4%	5%	8%	5%	6%
6	a	8%	7%	5%	5%	7%	5%	6%
7	a	13%	6%	3%	4%	7%	4%	6%
8	b	9%	5%	16%	8%	10%	8%	9%
9	b	8%	7%	4%	5%	6%	5%	5%
10	b	9%	7%	7%	11%	8%	11%	9%
11	b	12%	6%	12%	3%	10%	3%	7%
12	b	5%	3%	8%	4%	5%	4%	5%
13	b	4%	9%	5%	8%	6%	8%	7%
14	b	13%	9%	11%	14%	11%	14%	12%
15	b	17%	4%	9%	7%	10%	7%	9%
16	b	25%	14%	13%	28%	17%	28%	23%
17	b	15%	9%	10%	15%	11%	15%	13%
18	b	10%	7%	8%	7%	8%	7%	8%
19	c	7%	8%	24%	6%	13%	6%	9%
20	c	3%	3%	12%	4%	6%	4%	5%
21	c	16%	7%	21%	5%	15%	5%	10%
22	c	20%	6%	15%	22%	14%	22%	18%
23	c	9%	3%	6%	8%	6%	8%	7%
24	c	9%	4%	17%	8%	10%	8%	9%
25	c	7%	6%	4%	5%	6%	5%	5%
26	c	11%	5%	11%	12%	9%	12%	11%
27	c	13%	12%	20%	12%	15%	12%	14%
28	c	15%	9%	11%	9%	12%	9%	10%
29	c	10%	5%	4%	12%	7%	12%	9%
	Avg.	11%	7%	10%	9%	9%	9%	9%
	S.D	5%	3%	6%	6%	3%	6%	4%
	Min.	3%	2%	3%	3%	3%	3%	3%
	Max.	25%	14%	24%	28%	17%	28%	23%

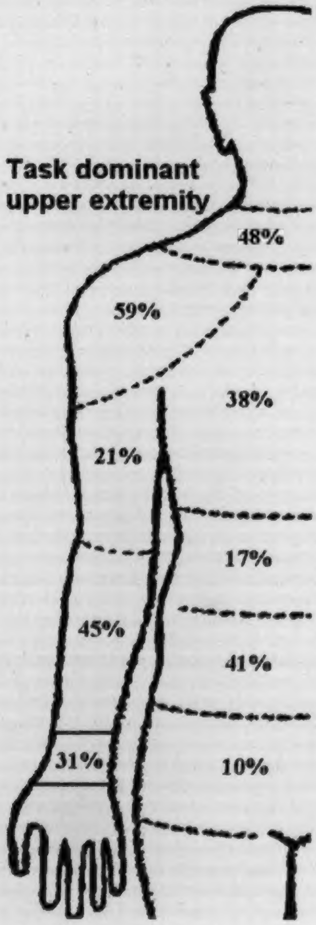
FCR – Flexor Carpi Radialis, FCU – Flexor Carpi Ulnaris, FDS- Flexor Digitorum Superficialis, PT- Pronator Teres

Table 8-7: Measures of exertion

			Electromyography	Psychophysical measures		
Subject	**Facility**	**Dynamic Force (N.)**	**% MVC**	**Borg turn**	**VAS str. demand**	**VAS overall demand**
1	a	40.46	7%	6	7.9	8.5
2	a	40.46	8%	7	8.4	6.6
3	a	40.46	3%	5	5.6	5.2
4	a	40.46	9%	8	8.5	8.7
5	a	40.46	6%	7	4.3	7.4
6	a	40.46	6%	7	6.6	6.7
7	a	40.46	6%	4	3.4	5.5
8	b	36.33	9%	5	5.3	5.3
9	b	36.33	5%	4	5.4	7.1
10	b	36.33	9%	3	1.4	2.2
11	b	36.33	7%	3	1.7	5
12	b	36.33	5%	3	4.8	4.7
13	b	36.33	7%	4	6.7	5.1
14	b	36.33	12%	3	3.2	2.4
15	b	36.33	9%	7	5.9	7.5
16	b	36.33	23%	4	4.9	5.7
17	b	36.33	13%	3	3.2	3.8
18	b	36.33	8%	5	6.8	7.7
19	c	39.42	9%	3	2.3	3
20	c	39.42	5%	5	7	6.5
21	c	39.42	10%	6	6.8	7.3
22	c	39.42	18%	5	4.2	5.2
23	c	39.42	7%	5	5.9	3.1
24	c	39.42	9%	3	6.8	6.3
25	c	39.42	5%	4	6.3	6.4
26	c	39.42	11%	7	5.9	8
27	c	39.42	14%	3	4.3	4.5
28	c	39.42	10%	3	3.8	7.7
29	c	39.42	9%	3	2.5	6.5
	Avg.	38.5	9%	4.7	5.2	5.8
	S.D	1.77	4%	1.61	1.94	1.78
	Min.	36.3	3%	3	1	2
	Max.	40.5	23%	8	9	9

Figure 8-1: Lumber grader

Figure 8-2: Body part discomfort ratings


Task dominant
upper extremity
48%
59%
38%
21%
17%
45%
41%
31%
10%

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Chapter 9 – Assessment of physical demands and comparison of multiple exposure definitions in a repetitive high risk sawmill occupation: saw-filer

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9.1 Introduction

Previous studies examining injury and illness trends in the Sawmill industry of Alberta, Canada have documented the enormous impact of musculoskeletal injuries (MSI). They accounted for 33% of total cost of Workers Compensation Board Claims and 38% of total time lost (Jones and Kumar, 2004a). Given the impact of MSIs industrial prevention efforts have focused on the identification and control of physical exposures. The control of physical exposures as a method of MSI prevention is justified as a number of probable theories linking MSI to physical exposures have been proposed, and evidence of a causal association between physical exposures and MSI has been well documented (NIOSH, 1997; Kumar, 2001). Industrial efforts seeking to control the incidence of MSI through the reduction in physical exposures use ergonomic risk assessments to direct intervention. Ergonomic risk assessments are able to account for the relative role of each physical exposure type (e.g., force, posture) in the precipitation of injury through an integrated model of MSI causation. Given the correct application of resources is dependent upon the identification of problem exposures there is a pressing need to accurately measure exposures and examine the predictive validity of the models used to derive an index of risk. In the recent past workplace exposure measurement was based on observation. Physical exposure measurement via observation is prone to significant measurement error (Lowe, 2004). Tools able to accurately and reliably measure physical exposures in the workplace are now available. The quantified nature of the information collected by tools such as electrogoniometers and surface electromyography allows the evaluator to use multiple definitions to describe the exposure. The ability to apply multiple definitions makes the description and examination of the equivalency of these definitions a prerequisite to an examination of the predictive validity of risk assessments. The objectives of this study were to: 1) describe the physical exposures in a sawmill job with a high incidence of upper extremity MSIs by multiple posture, exertion and frequency variable definitions and 2) examine the comparability of those multiple variable definitions. The saw filer position was selected for analysis of physical exposures given the high proportion of workers reporting upper extremity discomfort (60%) and the high average annual incidence of upper extremity musculoskeletal events recorded per person year worked (0.43) in the four facilities examined.

Few studies are available which describe MSI incidence in the forest products manufacturing industries. Silverstien and Hughes (1996) described the occurrence of musculoskeletal disorders in one pulp and paper manufacturing facility. Jones and Kumar (2004a,2004b,2005) described injury and illness trends in the pulp and paper, plywood and sawmill industries in Alberta, Canada; and, Jinadu (1990) described the 12 month history of injuries in the wood products manufacturing industries of Nigeria. No studies could be located which presented quantified physical demands or compared the results of multiple physical exposure variable definitions in this population.

9.2. Methods

9.2.1 Occupation identification

Deriving incidence rates for the saw-filer position using compensation information was not possible given information describing the complete work force was not available (Jones and Kumar, 2004a). For this reason the occupational health records of four sawmill facilities were consulted to determine which production positions were commonly associated with injuries of musculoskeletal nature to the upper extremity, and the saw-filer position was selected.

9.2.2 Task description

The primary function of the saw filer position is to maintain the condition of the round saws, band saws, and chipper blades (knives). The efficiency of the sawmilling process is dependent upon the condition of this equipment. The saw filer is responsible for repairing saw blades and knives during equipment breakdown and scheduled maintenance. Once the saw blades are removed, the blades and knives are sharpened via automated processes. Round saws require the saw filer remove imperfections in the saw by hammering the saw blade with a 1.13 kg. hammer. This same process is then repeated in order to tension the saw blade. Imperfection correction and tensioning requires the saw be placed on an anvil and hammered. Time required to correct imperfections and tension saws is variable and is dependent upon dimension and condition of the saw blade. The physical exposures described here were those measured during the hammering of round saws (imperfection correction and tensioning) only. The primary hammering task of the saw filer is illustrated in figure 9-1.

9.2.3 Subject selection

Male and female workers presently performing the saw-filer position between the ages of 18 and 65 were recruited at four sawmill facilities. Subjects were excluded from the study if they reported: injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. No female workers were present at the four facilities examined. 15 male subjects volunteered to take part in the study out of the population of 15 (100% participation rate).

9.2.4Body part discomfort index (Corlett and Bishop, 1976)

Each worker was asked to complete a body part discomfort survey prior to beginning data collection. Workers were provided a body map and asked to indicate any areas where discomfort is typically felt following a shift using the scale provided. Ratings ranged from 0 (indicating no discomfort) to 10 indicating the body region was "very uncomfortable". Ratings greater than 1 were taken to indicate discomfort.

9.2.5 Data collection

9.2.5.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to hammer round saws (task dominant upper extremity). Electrogoniometers were applied as per the users' manual recommendations (Biometrics, 2002). Prior to beginning data collection the subjects were asked to position their elbow at 90 degrees, their forearm in mid position (thumb positioned superiorly), and wrist in neutral position while the electrogoniometers were zeroed. A sample of 5 minutes was recorded during actual job performance. Angular displacement was recorded in 3 planes (X,Y,Z) with a synchronized bi-axial and uni-axial Biometrics ™ electrogoniometer simultaneously at 200 Hz. Postures and frequencies required to perform the job were determined through analysis of the recorded wave forms with the Biometrics Data link analysis software.

9.2.5.2 Exertion data acquisition

Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction and job simulated exertions. Only the upper extremity reported by the subjects as used to hold the hammer was assessed. The extensor carpi radialis (ECR) and flexor carpi radialis (FCR) were assessed for the radial deviation component and the flexor carpi ulnaris (FCU) was evaluated for the ulnar deviation component of the hammering task. Electrode placement was determined by isolating the muscle in question with manual muscle testing performed by a physical therapist and placing the electrode in approximately the midpoint of the muscle belly. The data acquisition system consisted of an analog-to-digital board with a 100-kHz sampling capacity. The EMG channels (4) were sampled at 1 kHz in real time. The EMG traces obtained during job simulated and maximum trials were full-wave rectified and linear envelope-detected from the raw EMG signals. From those processed traces, peak EMG and average EMG was measured using custom software developed by the Ergonomics Research Laboratory at the University of Alberta. The sampled signals were stored on a laptop computer. Data acquisition took place during a 9 second sample to cover the entire task cycle. Data from 2 seconds prior to the start of activity were used to discern a baseline, and 2 seconds following the 5 second test were used to allow the subject to return to baseline values.

9.2.5.2.1. Maximum voluntary contraction: During the MVC trials the subject was seated with the task dominant upper extremity positioned at the side and the elbow bent to 90 degrees. A cylindrical handle connected to an immobile base by a steel cable was either positioned in approximately 20 degrees of ulnar deviation (for the static radial deviation trial) or 10 degrees of radial deviation (for the static ulnar deviation trial). During MVC trials the subjects were instructed as follows: "When I say go, I want you to bring your force up to your maximum level over 2 seconds and hold for another 3 seconds." The subjects were given a rest period of a minimum of two minutes between trials.

9.2.5.2.2 Job simulated trial: Job simulated muscle activity was determined by having the subject maintain the 1.13 kg. hammer in a job simulated standardized static position. Subjects were tested in sitting with the wrist in neutral flexion/extension and 20 degrees of ulnar deviation (job simulated radial deviation) or 10 degrees of radial deviation (job simulated ulnar deviation). In job simulated trials the weight of the hammer was supported until the trial was begun. In the trial the weight of the hammer was supported entirely by the subject and maintained for approximately 5 seconds.

9.2.5.2.3 Psychophysical measure of exertion: Following data collection during job performance workers were asked to rate the upper extremity exertion required to hammer saws using a Borg Cr-10 scale and a Visual analog scale. The workers were also asked to rate the overall demand of the job using a Visual analog scale (Borg, 1982; Huskisson, 1983).

9.2.6 Data Analysis

9.2.6.1 Comparisons

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Kruskal Wallis H test (alpha level 0.05) was used to determine if significant differences existed between facilities on the exposure variables recorded (range of motion, %MVC, Borg scores, VAS scores, body part discomfort ratings). The Friedman test (alpha level of .05) was used to test whether significant differences existed between posture variable definitions (peak, repetition average, overall average). Associations between exertion variables (%MVC, Borg, VAS) were tested with the Spearman's rho rank correlation test (alpha level 0.05). Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

9.2.6.2. Motion

9.2.6.2.1 Posture: Postures required to perform the saw-filer position were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (hammering saws). The repetition average (Rep avg.) posture was defined by randomly selecting 10 repetitions (hammer strokes), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average (OA) posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample.

9.2.6.2.2 Duty cycle: The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

9.2.6.2.3 Frequency: Repetitions performed during the sample were determined by inspecting the radial/ulnar deviation waveform recorded by the bi-axial electrogoniometer. Radial/ulnar deviation was used to define repetition due to its cyclical nature in performance of the job (hammering saws) and clear repeated trace as recorded by the analysis system used.

9.2.6.2.4 Velocity and acceleration: The angular excursion and time of motion was recorded for 5 samples of the radial and ulnar deviation excursion taken to be representative of hammering a round saw for 3 subjects at each facility assessed and used to calculate average velocity and acceleration values. Only ½ of the cycle was considered as it was assumed after the hammer reached the mid point gravity would be responsible for the remainder of the force required to complete the hammer stroke. Angular excursion was divided by the time necessary to reach the midpoint of the cycle to arrive at the average velocity. The derived angular velocity was again divided by the time necessary to reach the midpoint of the cycle to arrive at the average acceleration.

9.2.6.3. Exertion

9.2.6.3.1 Electromyography: A sample of approximately 2 seconds of consistent activity from the 5 second trial was selected by reviewing the processed EMG signal of the primary agonist assessed according to the motion assessed (radial deviation – FCR, ulnar deviation-FCU). The job simulated radial and ulnar deviation values were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the radial and ulnar deviation components of the hammering task. An average % MVC value for the hammering task was then derived by averaging the radial and ulnar deviation sub component MVC scores.

9.2.6.3.2 Dynamic force applied: Dynamic force required to hammer saws was calculated assuming the center of mass of the hammer was in the middle of the hammer head. The inertial component of the force required was calculated using the average acceleration as described above.

9.3. Results

9.3.1 Incidence of upper extremity musculoskeletal injury

Alberta Workers Compensation Board data indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the saw-filer position. Incidence rates calculated based on person year estimates were available from three of the four facilities examined. Average incidence of reportable musculoskeletal events per person year worked ranged from 0.12 (facility A) to 0.86 (facility D) during the period assessed (1997-2002).

9.3.2 Subject characteristics

The average age of subjects was 44 (S.D. 9.5), average height of subjects was 178 cm (S.D. 7.5 cm), and average weight of subjects was 86.1 kg. (S.D. 14.84 kg.). Average work experience at the saw-filer position at time of assessment was 11.5 years (S.D. 6.83 yrs.).

9.3.3 Body part discomfort survey ratings

No significant differences in body part discomfort ratings were found specific to any body region between facilities. Discomfort reported by body region is presented in table 9-1. Percentage of the study population reporting discomfort (greater than 1 on a scale of 1-10) by body region is illustrated for the reader in figure 9-2.

9.3.4 Motion required

9.3.4.1 Posture/joint excursion

Peak, repetition average, and overall average range of motion endpoints recorded are listed in table 9-2. Total joint excursions by plane of motion are described in table 9-3. No significant differences existed between facilities assessed in any deviation angle measured by any definition of end range (i.e. peak, repetition average, or overall average) across the three planes of motion assessed. Significant differences (p<.05) did exist between facilities in radial/ulnar deviation joint excursion when end points were defined using repetition average values. Maximum mean angular differences between facilities in total joint excursion in the plane of radial/ulnar deviation were 10.2 degrees when repetition average end points were used. No significant differences in total joint excursion were observed between facilities in the planes of flexion/extension or pronation/supination when either the repetition average or peak endpoints were used. When all subjects were grouped total joint excursions in all planes of motion were significantly different (p<.001) when repetition average were substituted for peak excursions to define the end points of the total joint excursion. Reduction in total joint excursions of 81%, 80% and 92% in the planes of radial/ulnar deviation, flexion/extension and supination/pronation respectively were recorded when repetition average postures and not peak postures were used to define end points. Posture variable definitions examined were not equivalent.

9.3.4.2 Frequency of movements (hammering)

Descriptions of the observed frequencies of movement by facility examined are provided in table 9-4. Significant differences between facilities were found in the hours spent hammering round saws per day ($p<.05$), repetitions performed per day ($p<.05$) and total exposure ($p<.05$). Maximum mean differences observed between facilities in the hours per day (hrs/day), repetitions per day (reps/day) and total exposures were 5 hrs/day, 17,914 reps/day and 1.25 hrs respectively.

9.3.4.3 Average velocity and acceleration (hammer stroke)

Average velocity and acceleration values recorded were 46.3 degrees/second (S.D. 13.1 degrees/second) and 187.5 degrees/second^2 (S.D. 36.58 degrees/second^2). Derivation and resultant average velocity and acceleration values are reported in table 9-5. No significant differences existed between the facilities examined in either the average velocity or acceleration employed to turn the boards.

9.3.5 Exertion required

An average of 9.5% of MVC (S.D. 3.4%) of the forearm musculature assessed was required to manipulate the hammer used. An average of 3.7 (S.D. 1.96) points on the 10 point Borg Cr-10 scale was attributed to the exertion required to hammer round saws. Visual analog scores attributed to the strength demand of hammering saws and the overall demand of the saw-filer position were 4.9 (S.D. 1.43) and 5.3 (S.D. 1.19) respectively. No significant correlations were observed between % MVC required and any psychophysical measure of exertion. No significant correlation was found between the Borg score and either VAS measure. A significant correlation was observed between the VAS measure of strength demand of hammer and the overall job demand ($p<.01$, $r^2=0.54$). Percent MVC specific to muscle assessed and task component is presented for the reader in table 9-6. Exertion scores (%MVC and psychophysical ratings) are presented for the reader in table 9-7. No significant difference between facilities assessed were found in either %MVC required to manipulate the hammer or psychophysical ratings of exertion.

9.4. Discussion

9.4.1 Quantified measurement of physical exposures in the upper extremity

Initial calibration on uni-planar calibration jigs of the electrogoniometers used in this study through ranges of motion available anatomically revealed maximum errors of 2.33, 3.67 and 3.33 degrees in the planes of wrist radial/ulnar deviation, flexion extension, and pronation supination respectively. The results of our calibration study were similar to those previously reported by Shiratsu and Coury in 2003. Several studies have documented the increased accuracy resulting from measurement of wrist range of motion via electrogoniometry as compared to measurement based on observation (Lowe 2004, Ketola et al., 2001; Spielholz et al., 2001). Lowe 2004 reported a misclassification rate of 61% when peak wrist postures were evaluated using a six category scale and found no significant improvement in measurement accuracy based on the experience of the evaluator. Electrogoniometers are prone to error during simultaneous multi-plan motion however. Jonson and Johnson (2001) reported mean error in the planes of wrist radial and ulnar deviation of 6 ± 5 degrees resulting from multi-planar motion. Measurement error due to multi-planar motion appears to have played a role in this study as radial and ulnar deviation postures recorded were observed to frequently approach, if not exceed, full physiologic range (Magee, 1997). The effect of multi-planar motion on measurement accuracy was not evaluated as three dimensional calibration jigs were not available.

9.4.2 Measured physical demands

No significant differences were observed between facilities assessed in any of the measures of exertion recorded. No significant correlation was observed between % MVC required and any psychophysical measure of exertion. The lack of association between measures of exertion determined quantitatively and psychophysical measures makes the examination of exertion variable definition on model output necessary in those risk assessment models where either exertion measure may be used (Moore and Garg, 1995; Occhipinti, 1998). Total joint excursion defined by peak end points and repetition average endpoints was observed to be significantly different and therefore not comparable. The effect of posture variable definition on risk assessment model output should therefore also be evaluated. Total hours spent, total repetitions per day and total exposure differed significantly between facilities assessed. Interestingly the average annual incidence of recordable musculoskeletal events per person year worked varied in a similar pattern to the frequency variables. Facility D reported an incidence rate 7.4 times greater than facility A and 2.7 times greater than facility B (incidence rate information not available for facility C). Hours spent performing the hammering task, repetitions per day and total exposures in facility D were 2.7 and 3.2 (hours spent), 6.9 and 4.9 (total repetitions), and 5.0 and 4.7 (total exposure) times greater than in facility A and B respectively. Subjectively reported incidence rates appear significantly different and observed differences in exposure variables measured suggest a relationship to incidence of MSI. Our ability to further examine the relationship between incidence of MSI and exposure is limited in this study by the lack of comparability of the occupational health records from the facilities examined. Additional studies of the relationship between individual and combined exposures and incidence of MSI are needed based upon a standardized surveillance system. Such a system is not currently available in the sawmill industry of Alberta, Canada.

In assessing the significance of differences between facilities and the association between variables considered the sample size used is an important limitation of this study. The small samples compared make the evaluation of the assumptions upon which parametric statistics are based unreliable and thus require the use of non-parametric procedures. The power of the tests to detect differences and examine associations is therefore reduced. The sample obtained does represent the population of workers performing the saw-filer position at the time of assessment however.

9.5. Conclusion

The introduction of electrogoniometry and surface electromyography into worksite exposure measurement has enabled collection of quantitative physical exposure information at a level of reliability not previously attainable based on observation. The collection of quantified exposure information and the comparison of that information by multiple variable definitions has allowed us to demonstrate the relationships (or lack thereof) of commonly used exposure variable definitions. Calculation of ergonomic risk assessments based on quantified exposure information presented here is now necessary to examine the effect of variable definition on model output and predictive validity.

9.6. Acknowledgement

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Table 9-1: Reported discomfort by body region

Subject	Facility	Neck	Shld	Upper arm	Forearm	Wrist	Mid back	Upper L spine	Lower L spine	Pelvis
1	a	4	3	2	3	0	3	3	3	0
2	a	5	0	0	0	0	0	0	6	0
3	a	0	0	0	0	0	0	0	10	0
4	b	0	0	0	0	0	0	0	7	7
5	b	0	0	0	0	0	0	0	0	0
6	b	4	0	0	0	0	0	0	8	0
7	b	0	2	0	0	0	0	0	0	0
8	b	2	2	0	0	0	0	7	8	0
9	c	0	7	0	0	5	0	0	0	0
10	c	0	0	2	2	0	0	3	2	0
11	c	2	0	0	0	4	2	3	4	0
12	c	2	4	0	0	0	0	0	5	0
13	d	4	0	0	0	0	0	0	4	3
14	d	5	1	8	8	0	4	4	4	4
15	d	3	0	5	5	7	0	0	0	5
	Avg.	2	1	1	1	1	1	1	4	1
	S.D.	2.0	2.1	2.4	2.4	2.3	1.3	2.2	3.3	2.3
	Min.	0	0	0	0	0	0	0	0	0
	Max.	5	7	8	8	7	4	7	10	7

Table 9-2: End range of motion values by posture variable definition in degrees

		Radial deviation		Ulnar deviation			Flexion		Extension			Pronation		Supination		
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**OA**
1	a	19	-14	-42	-27	-20	80	13	-48	-8	0	54	18	-50	8	14
2	a	9	-12	-50	-30	-19	47	-11	-56	-37	-28	38	16	-40	6	10
3	a	12	-6	-40	-26	-14	41	4	-39	-30	-18	38	17	-35	9	13
4	b	19	-9	-27	-16	-12	71	14	-37	-8	1	41	-2	-51	-12	-7
5	b	24	-11	-26	-17	-14	48	17	-40	5	10	40	25	-48	22	23
6	b	13	-23	-49	-29	-26	42	-6	-58	-20	-14	21	4	-63	2	3
7	b	19	-8	-37	-15	-11	44	-1	-42	-19	-11	40	25	-40	21	23
8	b	19	-38	-50	-43	-41	69	7	-57	-2	1	48	20	-36	18	18
9	c	27	-8	-34	-19	-13	67	21	-43	1	10	37	16	-35	9	11
10	c	17	-12	-38	-25	-17	61	2	-51	-17	-10	46	11	-50	7	9
11	c	10	-25	-39	-32	-28	61	10	-51	-9	-3	56	42	-38	36	38
12	c	13	-15	-42	-31	-21	60	13	-38	-8	0	48	8	-56	-7	1
13	d	8	-13	-31	-24	-17	30	2	-40	-20	-13	44	28	-26	23	26
14	d	9	-12	-41	-18	-14	43	4	-25	-12	-6	27	20	-17	14	19
15	d	16	-20	-38	-25	-22	29	-3	-51	-15	-10	41	15	-37	11	13
	Avg.	16	-15	-39	-25	-19	53	6	-45	-13	-6	41	17	-41	11	14
	S.D.	5.7	8.3	7.4	7.5	7.7	15.3	9.0	9.1	11.3	10.3	9.1	10.4	11.8	12.1	11.1
	Min.	8	-37.7	-50	-43	-40.5	29	-11.2	-58	-37.4	-27.9	21	-1.8	-63	-12.3	-7
	Max.	27	-6	-26	-14.7	-10.9	80	20.9	-25	5.3	10	56	41.5	-17	36	38.4

Rep avg.- Repetition Average, OA- Overall Average
Negative values indicate end range of motion in ulnar deviation, extension, or supination.

Table 9-3: Total joint excursion values by end range posture variable definition in degrees

		Radial /Ulnar deviation		Flexion / Extension		Pronation / Supination	
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**
1	a	61	13	128	21	104	10
2	a	59	18	103	26	78	11
3	a	52	20	80	34	73	8
4	b	46	7	108	22	92	11
5	b	50	6	88	12	88	4
6	b	62	6	100	14	84	2
7	b	56	7	86	18	80	3
8	b	69	5	126	8	84	2
9	c	61	11	110	20	72	7
10	c	55	13	112	19	96	5
11	c	49	7	112	19	94	6
12	c	55	17	98	21	104	14
13	d	39	11	70	21	70	5
14	d	50	6	68	16	44	6
15	d	54	5	80	12	78	3
	Avg.	55	10	98	19	83	6
	S.D.	7.39	5.02	18.76	6.27	15.23	3.66
	Min.	39	4.67	68	8.4	44	1.7
	Max.	69	19.6	128	33.9	104	14.4

Table 9-4: Frequency variables recorded

Subject	**Facility**	**Duty cycle**	**Reps/min**	**Hrs/day**	**Reps/day**	**Total exposure (Hrs.)**
1	a	4%	7	4.95	2147	0.22
2	a	23%	38	1.35	3117	0.32
3	a	22%	36	1.8	3844	0.39
4	b	13%	28	2.8	4685	0.36
5	b	12%	25	2.31	3486	0.27
6	b	10%	22	2.31	3038	0.23
7	b	17%	37	2.31	5097	0.39
8	b	22%	49	1.75	5097	0.39
9	c	32%	40	4.5	10694	1.42
10	c	17%	21	5.4	6935	0.92
11	c	17%	22	3.6	4726	0.63
12	c	14%	18	3.6	3859	0.51
13	d	15%	33	4	7991	0.59
14	d	18%	40	9	21382	1.59
15	d	28%	62	9	33478	2.49
	Avg.	18%	31.8	3.9	7972	0.71
	S.D	7%	13.53	2.39	8505	0.64
	Min	4%	7.23	1.35	2147	0.22
	Max	32%	62.00	9.00	33478	2.49

Table 9-5: Average displacement, duration, velocity and acceleration values used to hammer saws

	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Repetition 5		Avg. Velocity	Avg. Accel.
Facility	Displacement (deg)	Time (sec)	Displacement	Time	Displacement	Time	Displacement	Time	Displacement	Time	deg/sec	deg/sec^2
a	18	0.30	16	0.26	14	0.29	22	0.33	15	0.30	57	194
a	22	0.30	19	0.32	18	0.28	17	0.28	23	0.42	62	195
a	22	0.26	16	0.25	22	0.33	13	0.28	19	0.30	65	229
b	5	0.17	6	0.15	5	0.16	4	0.13	6	0.13	36	240
b	6	0.17	5	0.19	6	0.20	7	0.19	8	0.17	35	191
b	5	0.16	5	0.16	4	0.12	5	0.12	4	0.16	33	226
c	9	0.27	10	0.27	12	0.27	12	0.27	12	0.30	40	144
c	8	0.35	13	0.35	15	0.27	14	0.31	13	0.27	42	135
c	24	0.19	20	0.39	21	0.37	15	0.36	17	0.28	67	212
d	12	0.30	10	0.25	12	0.29	10	0.28	8	0.24	38	140
d	11	0.28	9	0.21	14	0.25	11	0.23	11	0.24	46	192
d	5	0.20	4	0.20	17	0.27	5	0.13	8	0.32	34	153

Table 9-6: Percentage of maximum voluntary contraction by muscle assessed and task component

		% MVC			Component values		Task average
Subject	**Facility**	**ECR**	**FCR**	**FCU**	**Radial**	**Ulnar**	**Overall average**
1	a	9%	8%	16%	9%	16%	12%
2	a	19%	7%	8%	13%	8%	10%
3	a	7%	6%	14%	6%	14%	10%
4	b	10%	8%	8%	9%	8%	9%
5	b	6%	8%	6%	7%	6%	7%
6	b	12%	4%	10%	8%	10%	9%
7	b	9%	6%	11%	8%	11%	10%
8	b	9%	2%	6%	5%	6%	5%
9	c	16%	17%	11%	16%	11%	13%
10	c	3%	7%	6%	5%	6%	5%
11	c	4%	8%	13%	6%	13%	10%
12	c	21%	20%	11%	21%	11%	16%
13	d	4%	4%	3%	4%	3%	3%
14	d	12%	10%	12%	11%	12%	11%
15	d	5%	15%	16%	10%	16%	13%
	Avg.	10%	9%	10%	9%	10%	10%
	S.D.	6%	5%	4%	5%	4%	3%
	Min.	3%	2%	3%	4%	3%	3%
	Max.	21%	20%	16%	21%	16%	16%

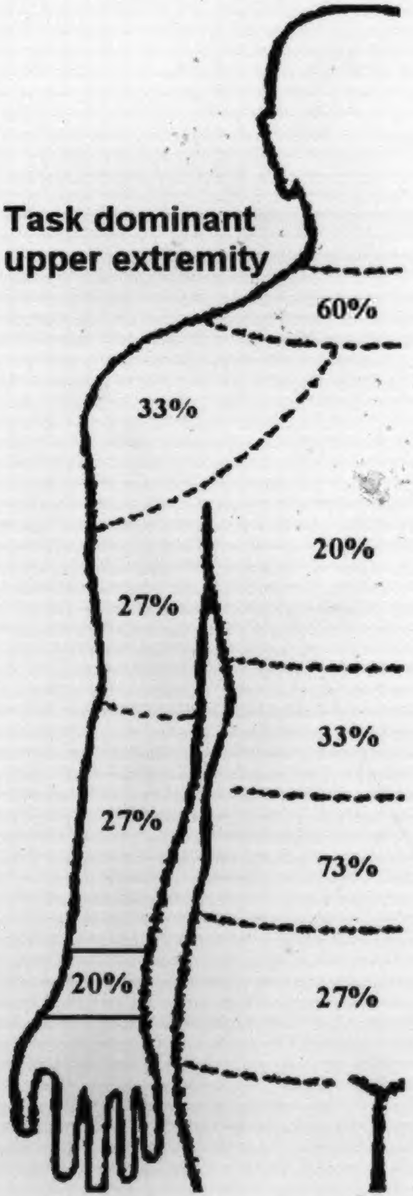
ECR_ Extensor carpi radialis FCR – Flexor Carpi Radialis, FCU – Flexor Carpi Ulnaris

Table 9-7: Measures of exertion

			Electromyography		Psychophysical measures	
Subject	**Facility**	**Dynamic Force (N.)**	**% MVC**	**Borg hammer**	**VAS str. demand**	**VAS overall demand**
1	a	11.86	12%	3	3.3	3.5
2	a	11.86	10%	3	3	5.4
3	a	11.86	10%	0.5	4.7	4.4
4	b	11.91	9%	7	7.3	7
5	b	11.91	7%	3	5.9	4.8
6	b	11.91	9%	8	4.8	4.6
7	b	11.91	10%	3	7.1	7
8	b	11.91	5%	4	3.8	4.2
9	c	11.70	13%	4	5.8	6.2
10	c	11.70	5%	4	3.9	5.2
11	c	11.70	10%	2	4.2	5
12	c	11.70	16%	2	4.8	5
13	d	11.69	3%	5	5	6
14	d	11.69	11%	5	6.7	7
15	d	11.69	13%	2	2.8	3.4
	Avg.	11.8	10%	3.7	4.9	5.2
	S.D.	0.11	3%	1.96	1.44	1.19
	Min.	11.7	3%	0.5	2.8	3.4
	Max.	11.9	16%	8.0	7.3	7.0

Figure 9-1: Saw-filer

Figure 9-2: Body part discomfort ratings


Task dominant upper extremity
60%
33%
20%
27%
33%
27%
73%
20%
27%

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Chapter 10 – Assessment of physical exposures and comparison of exposure definitions in a repetitive sawmill occupation: trim-saw operator

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10.1 Introduction

Musculoskeletal injuries in the upper extremity accounted for 1698 Workers Compensation Board claims in the sawmill industry of Alberta, Canada from 1997-2002 (Jones and Kumar 2004a). Musculoskeletal injuries accounted for 33% of the total cost of claims and 38% of the total time lost due to claim in the same period. Estimates of the rate of recordable upper extremity musculoskeletal incidents in the trim saw operator position ranged from 0.17 to 0.77 per person year worked in the facilities examined. Given the impact of musculoskeletal injuries industrial prevention efforts now seek to identify the physical exposures which precipitate injury. The U.S. National Institute for Occupational Safety and Health has identified evidence of the association between workplace physical exposures incidence of musculoskeletal injuries (MSI) and Kumar (2001) has proposed a number of probable mechanisms of injury (US Department of Health and Human Services 1997, Kumar 2001). Given both the established relationship between workplace physical exposures and MSIs and the presence of probable mechanisms of injury the control of physical exposures as a method of preventing MSI is justified. Industrial prevention efforts commonly make use of these ergonomic risk assessment techniques to identify problem exposures and direct intervention. Unfortunately, little agreement currently exists between authors as to which exposures should be considered and the relative role of those exposures in the precipitation of injury (Jones and Kumar 2004b). As a result of this disagreement there is a pressing need to examine the comparability of the proposed ergonomic risk assessment techniques and their relationship to incidence of injury.

In the past our ability to examine the comparability of ergonomic risk assessment techniques has been limited by a lack of accurate and reliable workplace exposure information. Several recent studies have described the meaningful measurement errors resulting from exposure information being collected via observation. Lowe (2004) examined the ability of worksite evaluators to correctly classify forearm and wrist posture and found rates of misclassification ranged from 22% to 70% when compared to measurements made by electrogoniometers (Lowe 2004). Bao et al. (2006) found limited correlations between frequency classifications made by ergonomists based on observation and measurements based on detailed time studies (Bao et al. 2006). The implications of an inaccurate assessment of physical exposures used in an assessment of risk are: the incorrect risk classification of a job and/or the misidentification of problem exposures for intervention. The use of surface electromyography and electrogoniometry in workplace exposure measurement increases the accuracy and reliability of the exposure assessment. The use of quantified exposure information in comparisons of ergonomic risk assessment output will therefore reduce measurement error and improve the validity of the comparisons. No studies could be located which compare the results of ergonomic risk assessment techniques based on quantified exposure information.

Traditionally, exposure assessments to be used in an ergonomic risk assessment have been collected via observation. Multiple posture and exertion variable definitions are available to the worksite evaluator performing an observation based exposure assessment. Based on observation the worksite evaluator may define posture according to the peak posture observed, peak posture required in the primary task only, or most frequently occurring posture. The collection of quantified exposure information allows the comparability of these definitions to be examined. Multiple definitions of the exertion variable may also be used in ergonomic risk assessment techniques (Moore and Garg 1995, Occhipinti 1998, University of Michigan 2005). Collection of both the percentage of maximum voluntary contraction (%MVC) required and the workers assessment of perceived exertion allows the association between the measured muscle activity and psychophysical perceptions of exertion to be examined. The ability to apply multiple definitions to the exposure variables considered by ergonomic risk assessment techniques makes the description and examination of the equivalency of these definitions necessary. Examination of the effect of multiple posture and exertion variable definitions on the ergonomic risk assessment output is then necessary to gain insight into optimal exposure definitions. No studies could be located which sought to describe the effect of substituting variable definitions on ergonomic risk assessment techniques.

It is the intent of this paper to describe the physical exposures required to perform a high risk sawmill job by multiple definitions of posture, exertion and frequency and examine the comparability of those definitions. Electrogoniometers and surface electromyography have been used to quantify the exposures in order to reduce measurement error. The definitions of the exposure variables examined have been chosen to reflect those available to worksite evaluators performing observation based assessments. The definitions used also reflect those required to apply ergonomic risk assessment techniques. Differences in exposures between facilities were examined in an effort to explain meaningful differences in recorded incidence rates between facilities. The comparability of ergonomic risk assessment techniques, calculated based on quantified demands, and the effect of altering variable definition will be examined in a subsequent paper.

10.2. Methods

10.2.1 Occupation identification

Deriving incidence rates specific to the trim-saw position using compensation information is not possible given information describing the complete work force is not available (Jones and Kumar 2004a). For this reason the occupational health records of the four sawmill facilities participating were consulted to determine which production jobs were commonly associated with musculoskeletal injuries to the upper extremity. Based on the review of occupational health records the trim-saw position was selected.

10.2.2 Task description

The trim-saw operator is responsible for sorting and positioning boards which have been cut into width dimension. Following sorting the rough width dimension boards enter the trim-saw to be cut into rough length dimension. Dimensional lumber arriving at the trim-saw operator position must be frequently turned to position the round side or "wane" superiorly. Turning boards is the primary task of the trim-saw operator; however, he/she may also be required to push, pull and lift boards (position boards) to cause them to fall to conveyors below. Figure 10-1 depicts the primary board turning task of the trim-saw operator.

10.2.3 Subject selection

Male and female workers presently performing the trim-saw position ages 18-65 were recruited at the four sawmill facilities studied. Subjects were excluded from the study if they reported: injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. No female workers were present at the four facilities examined. 33 male subjects volunteered to take part in the study out of the population of 33 (100% participation rate). Complete data sets were not obtained for 4 subjects therefore 29 subjects are included in the analyses described.

10.2.4 Body part discomfort survey (Corlett and Bishop 1976)

Each worker was asked to complete a body part discomfort rating survey prior to beginning data collection. Survey ratings ranged from 1 indicating "no discomfort" to 10 indicating the body region is "very uncomfortable". Ratings greater than 1 were taken to indicate discomfort.

10.2.5 Data collection

10.2.5.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm of the upper extremity used to turn boards (primary task) during job performance. The trim saw operator may be required to use either the left or the right upper extremity to perform the primary task dependent upon the direction of industrial flow. Only the upper extremity used to perform the primary task (task dominant upper extremity) was assessed. Biometrics™ bi-axial SG-65 and uni-axial Q-150 electrogoniometers were applied as per the users' manual recommendations

(Biometrics 2002). Prior to beginning data collection the subjects were asked to position their elbow at 90 degrees, their forearm in mid position (thumb positioned superiorly), and wrist in neutral position (0 degrees in the plane of flexion/extension and radial/ulnar deviation) while the electrogoniometers were zeroed. A sample of 5 minutes was recorded during actual job performance. Angular displacement was recorded in 3 planes (X,Y,Z) with a bi-axial and uni-axial Biometrics ™ electrogoniometer at 200 Hz. Postures and frequencies required to perform the job were determined through analysis of the recorded wave forms with the Biometrics Data link analysis software.

10.2.5.2 Exertion data acquisition

Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction (MVC) and job simulated exertions in static trials performed off the production line. Only the upper extremity used to perform the primary task (task dominant upper extremity) was assessed. The flexor carpi radialis, flexor carpi ulnaris, and flexor digitorum superficialis were assessed for the flexion component and the pronator teres was evaluated for the pronation component of the board flip task. Electrode placement was determined by isolating the muscle in question with manual muscle testing performed by a physical therapist and placing the electrode at approximately the midpoint of the muscle belly. A Delsys Bagnoli 8 EMG system was used to record the muscle activity of all muscles assessed in each trial (Delsys 2002). Single differential bipolar electrodes with parallel bar shaped silver detection surfaces (1 cm length x 1mm width) spaced 1 cm apart were used in the experimental trials and oriented perpendicular to the muscle fibers. The data acquisition system consisted of an analog-to-digital board with a 100-kHz sampling capacity. The EMG channels (4) were sampled at 1 kHz in real time. The sampled signals were stored on a laptop computer. The EMG traces obtained during job simulated and maximum trials were full-wave rectified and linear envelope-detected from the raw EMG signals. From those processed traces, peak EMG and average EMG was measured using custom software developed by the Ergonomics Research Laboratory at the University of Alberta. Data acquisition took place during a 9 second sample to cover the entire task cycle. 2 seconds prior to the assessors instructions to begin were used to record a baseline activity and 2 seconds following the 5 second test were used to allow the subject to return to baseline values. Experimental trials were administered in random order to allow differences observed to be attributed to differences in the experimental conditions and not the order of trials. A minimum of 2 minutes rest was given to subjects between trials to prevent fatigue. Two trials were performed for each condition with the second trial being recorded to allow the subject to become familiar with the task.

10.2.5.2.1 Maximum voluntary contraction trial: Maximum voluntary contraction trials were performed in a location removed from the industrial process (e.g. coffee room) within the facility. During the MVC trials the subject was seated with the task dominant upper extremity positioned at the side and the elbow bent to 90 degrees. An isometric exertion in either a flexion or rotational direction on a handle made from a piece of dimensional lumber connected to an immobile base by a steel cable was performed dependent upon the trial (wrist flexion or pronation). During flexion trials the steel cable was connected to the middle of the handle and the subject was instructed to perform a static flexion exertion. During the pronation trial an alternate handle to which the steel cable was attached to the outside edge was used and the subject was instructed to exert a static rotational exertion on the handle. During MVC trials the subject was instructed as follows: "When I say go, I want you to bring your force up to your (maximum level) over 2 seconds and hold for 3 seconds or until I say stop."

10.2.5.2.2 Job simulated trial: Job simulated trials were performed in a location removed from the industrial process (e.g. coffee room) within the facility. Job simulated muscle activity was determined by having the subject maintain a representative board (5.1 cm. deep by 20.3 cm. wide, 488 cm. long) in a job simulated standardized static position while muscle activity was recorded. Subjects were tested in standing with the wrist in neutral flexion/extension and supinated position (job simulated flexion) or slightly pronated from full supination position (job simulated pronation). The height of the mock up table was adjusted such that the subject maintained the board at an angle of approximately 3 degrees from the horizontal plane of the mock up table at 90 degrees of elbow flexion (figure 10-2). In job simulated trials the weight of the representative board was supported by the assessor until the trial was begun. After the trial was begun the weight of the representative board was given to the subject and maintained for approximately 5 seconds until removed by the assessor.

10.2.5.2.3 Psychophysical measure of exertion: Following motion data collection during job performance workers were asked; "whether during the cycle there were job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the actions from one to ten using the Borg CR-10 scale (Borg 1982). Workers were also asked to rate the strength demand required to turn the boards and the overall job demand on a 10 cm. visual analog scale (Huskisson 1983).

10.2.6 Data Analysis

10.2.6.1 Comparisons and associations

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Kruskal Wallis H test (alpha level 0.05) was used to determine if significant differences existed between facilities on the exposure variables recorded (range of motion, %MVC, Borg scores, VAS scores, body part discomfort ratings). The Friedman test (alpha level of .05) was used to test whether significant differences existed between posture variable definitions (peak, repetition average, overall average). Associations between exertion variables (%MVC, Borg, VAS) were tested with the Spearman's rho rank correlation test (alpha level 0.05). Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

10.2.6.2 Motion

10.2.6.2.1 Posture: Postures required to perform the trim-saw operator position were defined based on three criteria. The peak posture was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak posture represents the maximum excursion observed and may not have taken place during a repetition of the primary task (turning boards). The repetition average posture was defined by randomly selecting 10 repetitions (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally the overall average posture was calculated considering all motions in the plane of interest for the entire sample. Overall average posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample.

10.2.6.2.2 Duty cycle: The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

10.2.6.2.3 Frequency: Repetitions of the primary task performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees at the proximal radio-ulnar joint. Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used. A change in direction of 18 degrees was selected by inspecting both the electrogoniometer output and simultaneous video of the job being performed and subjectively selecting the cut-point which differentiated between cycles of the primary task. Every time a motion exceeded the threshold value it was counted. The sum of these numbers over the sample time provided the frequency variable.

10.2.6.2.4 Velocity and acceleration: The angular excursion and time of motion was recorded for 5 samples of the supination/pronation excursion taken to be representative of flipping a board for 3 subjects at each facility assessed and used to calculate average velocity and acceleration values. Average velocity and acceleration were calculated by this method to enable the inertial component of the force necessary to perform the primary task to be calculated. Average values and not peak values were of interest as a "typical value" accounting for the variation in board dimension typically present was desired. Only ½ of the cycle was considered as it was assumed after the board reached the mid point gravity would be responsible for the remainder of the force required to complete the "flip". Single and double differentiating the displacement vs. time was used to calculate velocity and acceleration respectively.

10.2.6.3 Exertion

10.2.6.3.1 Percentage of maximum voluntary contraction: A sample of approximately 2 seconds of consistent activity from the 5 second trial was selected by reviewing the processed EMG signal of the primary agonist assessed according to the motion assessed. The average value resulting from the muscles assessed during the job simulated flexion trial and the job simulated pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the flexion and pronation components of the task.

10.2.6.3.2 Dynamic force applied: Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration as described above.

10.3 Results

10.3.1 Incidence of upper extremity musculoskeletal injury

The Alberta Workers Compensation Board data set indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the trim-saw operator position. Insufficient resolution was present in the occupation title field of the compensation board database to identify specific sawmill production jobs. For this reason the occupational health records of the four facilities participating were reviewed for the same period (1997-2002). Incidence rates, specific to the trim-saw operator, calculated based on person year estimates from the four facilities averaged 0.17 to 0.77 recordable upper extremity incidents of a musculoskeletal nature per person year.

10.3.2 Subject characteristics

The average age of subjects was 31 years (S.D. 8.2 years), average height of subjects was 180 cm (S.D. 6.7 cm), and average weight of subjects was 88.1 kg. (S.D. 12.9 kg.). Average work experience at the trim-saw position at time of assessment was 3.5 years (S.D. 4.1 yrs.). Only average height of the subjects was significantly different ($p<.05$) across the facilities assessed (maximum differences in mean height between facilities was 10.2 cm.).

10.3.3 Body part discomfort survey ratings

38 % of the subjects evaluated reported discomfort of greater than moderate discomfort (greater than 4 on a scale of 0 to 10) in the task dominant upper extremity. Reported discomfort by body region is described in table 10-1. No significant differences in reported discomfort in the task dominant upper extremity were found across facilities assessed. Percentage of the study population reporting discomfort (greater than 1 on a scale of 0-10) by body region is illustrated for the reader in figure 10-3.

10.3.4 Motion required

10.3.4.1 Posture/joint range of motion

Peak, repetition average, and overall average ranges of motion observed in the recorded sample are listed in table 10-2 by plane of motion. No significant differences existed between facilities in any wrist range of motion. Total range of motion in each plane was significantly different ($p<.05$) when repetition average values were substituted for peak range of motion to define end points. Reduction in total ranges of motion of 51%, 52% and 66% in the planes of radial/ulnar deviation, flexion/extension and supination/pronation were recorded respectively when repetition average postures and not peak postures were used to define end points. Total ranges of motion by end range definition are described for the reader in table 10-3.

10.3.4.2 Frequency of movements (board turning)

Descriptions of the observed frequencies of movement by facility examined are provided in table 10-4. Significant differences ($p<.01$) between facilities were found in repetitions per day, hours worked per day, % of cycle spent performing reps (duty cycle), and total exposure (total exposure = hrs/day x duty cycle). Maximum mean differences observed between facilities in repetitions per day (reps/day), hours worked per day (hrs/day), % of cycle spent performing reps (duty cycle), and total exposure were; 10,911 reps/day, 6.6 hrs/day, 10% and 1.68 hrs. respectively. Average velocity and accelerations employed to turn the boards were 130 degrees/sec (S.D. 20.83) and 293 degrees/sec^2 (S.D. 65.97) respectively. No significant differences were found between facilities with respect to the average velocities or accelerations applied to turn boards. Derivation and resultant average velocity and acceleration values are reported in table 10-5.

10.3.5 Exertion required

An average of 33% of MVC (S.D. 11%) was required to turn a representative board (5.1 cm. deep by 20.3 cm. wide, 488 cm. long). Representative board weights upon which the job simulated MVC testing was performed varied from 16.4 to 18.6 kgs. Significant differences ($p \leq .05$) were observed in the percentage of MVC required to perform the job between facilities. Mean %MVC values ranged from 22-42% of MVC. Facilities tested with higher weight representative boards did not consistently display higher %MVC values. Differences in required %MVC were also not explained by differences in subject characteristics as only the height of the subjects differed significantly across facilities assessed and again the trend did not follow the trend of increasing or decreasing %MVC values. No significant difference was found across facilities assessed with respect to reported Borg scores or reported VAS strength demand scores specific to turning boards. Significant differences were observed across facilities assessed with respect to the VAS rating of overall job demand ($p<.05$). No association was observed between the VAS ratings of overall job demand and measured %MVC or any frequency variables. No significant association was observed between %MVC required and psychophysical measure of exertion. % MVC specific to muscle assessed is presented for the reader in table 10-6. Exertion scores (%MVC and psychophysical ratings) are presented for the reader in table 10-7.

10.4. Discussion

10.4.1 Quantified physical exposures

In the past the accuracy of workplace physical exposure measurement has been affected by measurement error resulting from assessment via observation (Ketola et al. 2001, Spielholz et al. 2001, Lowe 2004). Use of electrogoniometers and surface EMG stands to significantly increase the accuracy and reliability of exposure assessment. Initial calibration of the electrogoniometers on uni-planar jigs through ranges reflecting those available physiologically revealed maximum errors of 2.33, 3.67, and 3.33 degrees in the planes of wrist radial/ulnar deviation, flexion/extension, and pronation/supination respectively. The results of our calibration studies were similar to those previously reported by Shiratsu and Coury (2003). Importantly, error due to motion in multiple planes of wrist motion simultaneously was not assessed in this study. Measurement error in radial and ulnar deviation due to motion in multiple planes has been reported by Jonson and Johnson (2001) to be 6 ± 5 degrees . Error due to multi-planar motion appears to have been important as peak wrist radial and ulnar deviation angles recorded in this study often approached and/or exceeded ranges reported as normal (Magee 1997).

10.4.2 Measured physical exposures

No significant differences were found between facilities in any of the wrist and forearm range of motion variables. The lack of significant differences between facilities examined enabled the grouping of all subjects to allow the examination of the effect of the different posture variable definitions used. Posture variable definitions examined were shown to be significantly different dependent upon endpoints selected and therefore not equivalent. Future studies which examine the effect of posture variable definition on ergonomic risk assessments which consider posture are needed. No association was found between %MVC required to turn a representative board and any psychophysical measure of exertion. The lack of association between %MVC and psychophysical ratings of exertion suggests future studies examining the effect of exertion variable definition on ergonomic risk assessments which allow exertion to be defined using %MVC or Borg scores are needed (Moore and Garg 1995, Occhipinti 1998, University of Michigan 2005). Future studies examining the effect of varying posture and exertion variables on risk assessment methods are needed as the variable definition may effect the predictive validity of the assessment.

10.4.3 Limitations

Measurement error resulting from simultaneous multi planar motion was not controlled in this study. Additionally, only 5 minutes of job performance was recorded with electrogoniometers and assumed to be representative of the task. The repetitive nature of the job which enabled the analysis of approximately 115 primary task cycles per subject significantly improves the representativeness of the sample as compared to that collected by observation however. While the assessment of motion took place during actual job performance assessment of exertion required was based on a static assessment of a job simulated activity. While the validity of using the results of static EMG assessment to indicate the demand of a dynamic task is questionable, the requirement that the assessment be normalized to the subject (enabling comparison across subjects) and reliably performed across subjects necessitates the use of a static assessment. Normalization of muscle activity enabling derivation of %MVC requires job simulated and maximum trials be performed in the same position(s) or motion(s). Normalization of a dynamic EMG assessment requires standardized positions or movements not representative of a dynamic non standardized task. Given both a static and dynamic assessment require standardization for normalization the ability of both techniques to capture muscle activity required to perform a non standardized task is in question. Further, muscle activity required to produce a given tension varies according to length of the muscle and velocity at which the task is performed. Normalization of a dynamic assessment requires therefore that the positions (motions) and velocity of the assessment be standardized for a non standardized task.

In assessing the statistical significance of differences across facilities assessed the sample size considered is an important limitation of this study. The small samples compared make the evaluation of assumptions upon which parametric statistics are based difficult and thus require use of non-parametric procedures. The power of the tests to detect differences and examine associations is therefore reduced.

The resolution of the compensation data set and the incomparability of the surveillance systems of the four facilities participating are also important limitations of this study. While seemingly significant differences exist between facilities with respect to incidence rates our confidence in this finding as well as our ability to examine the relationship between differences in exposure recorded and differences in incidence is restricted by our ability to group the information. Additional studies of the relationship between individual and combined exposures and incidence of MSI are needed based upon a standardized surveillance system. Such a system is not currently available in the sawmill industry of Alberta, Canada.

10.5 Conclusion

Use of electromyography and electrogoniometry to assess physical exposures required to perform a job has enabled measurement of physical exposures at a level of resolution not possible through observation. Quantification of physical exposures has demonstrated that significant differences exist between exposure variable definitions available to worksite evaluators performing exposure assessments by observation. Calculation of risk assessments with multiple variable definitions is necessary to determine if varying posture and exertion variable definition results in significantly different risk index scores.

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Table 10-1: Reported discomfort by body region

Subject	Facility	Neck	Shld	Upper arm	Forearm	Wrist	Mid back	Upper L spine	Lower L spine	Pelvis
1	a	0	0	0	0	0	0	0	5	0
2	a	0	0	0	0	0	0	0	0	0
3	a	0	0	0	3	6	0	0	0	0
4	a	0	0	0	0	0	0	0	5	0
5	a	0	0	0	0	0	0	0	0	0
6	a	0	5	5	5	0	0	0	2	0
7	a	3	0	0	0	0	0	0	0	0
8	a	5	0	0	0	0	2	2	2	0
9	a	5	0	7	7	5	0	0	0	0
10	a	5	0	0	0	0	2	0	7	0
11	b	3	0	0	0	0	3	3	4	1
12	b	0	0	0	0	0	0	0	0	0
13	b	3	3	3	3	0	3	3	3	3
14	b	0	0	0	0	0	3	0	0	0
15	b	0	0	0	0	0	0	0	0	0
16	c	0	0	0	5	0	0	0	5	0
17	c	5	0	6	6	9	0	0	0	0
18	c	0	0	0	0	2	0	0	0	0
19	c	0	0	0	0	0	0	0	0	0
20	c	0	0	0	0	7	0	0	2	0
21	c	5	5	0	0	0	0	4	5	0
22	c	9	9	10	10	8	0	7	7	0
23	c	5	0	0	0	0	0	0	3	0
24	d	0	0	0	0	0	0	0	3	6
25	d	0	3	0	0	4	0	0	0	0
26	d	0	0	0	6	6	2	0	0	0
27	d	0	0	0	0	0	0	0	0	0
28	d	0	0	0	0	7	0	0	0	0
29	d	0	0	0	0	0	0	0	5	0
	Avg.	2	1	1	2	2	1	1	2	0
	S.D	2.53	2.13	2.58	2.80	3.04	1.06	1.63	2.41	1.23
	Min.	0	0	0	0	0	0	0	0	0
	Max.	9	9	10	10	9	3	7	7	6

Table 10-2: End range of motion values by posture variable definition in degrees

		Radial deviation		Ulnar deviation			Flexion		Extension			Pronation		Supination		
Subject	Facility	Peak	Rep avg.	Peak	Rep avg.	OA	Peak	Rep avg.	Peak	Rep avg.	OA	Peak	Rep avg.	Peak	Rep avg.	OA
1	a	28	15	-40	-25	-5	20	-5	-70	-67	-37	53	44	-30	-15	18
2	a	7	-5	-42	-30	-17	29	8	-64	-45	-18	61	42	-45	-22	12
3	a	27	8	-45	-25	-7	43	14	-64	-47	-22	62	52	-40	-15	23
4	a	13	5	-48	-33	-19	70	47	-65	-31	-2	49	33	-53	-37	6
5	a	14	5	-55	-34	-16	35	-1	-83	-56	-30	49	36	-38	-25	4
6	a	12	3	-47	-29	-11	40	17	-61	-44	-12	52	38	-27	-22	1
7	a	17	2	-38	-30	-14	72	27	-55	-22	3	61	41	-33	-18	17
8	a	15	4	-42	-37	-15	55	16	-67	-48	-15	34	25	-48	-37	0
9	a	23	7	-65	-31	-11	48	17	-76	-53	-17	47	31	-26	-13	8
10	a	24	7	-48	-32	-13	74	30	-64	-41	-8	38	24	-34	-21	2
11	b	11	-1	-44	-29	-14	37	19	-54	-37	-10	33	10	-58	-42	-16
12	b	11	-2	-43	-36	-20	45	14	-57	-44	-14	53	36	-50	-36	0
13	b	25	8	-45	-30	-11	54	15	-73	-39	-12	45	37	-29	-13	11
14	b	14	-11	-63	-48	-28	69	26	-62	-31	-5	46	28	-60	-35	-4
15	b	20	16	-48	-19	8	38	32	-11	-2	16	36	26	-41	-23	0
16	c	10	-3	-27	-21	-12	21	0	-63	-40	-19	51	44	-29	-21	10
17	c	14	2	-39	-28	-13	56	23	-77	-45	-12	40	24	-53	-29	-3
18	c	28	9	-35	-21	-6	67	14	-51	-37	-13	50	29	-35	-16	7
19	c	15	-3	-43	-30	-17	56	4	-76	-48	-18	43	22	-51	-39	-6
20	c	9	-5	-35	-26	-15	30	7	-55	-31	-11	50	38	-44	-17	12
21	c	23	14	-62	-24	-5	79	23	-62	-38	0	43	35	-62	-23	4
22	c	17	1	-45	-27	-12	50	30	-55	-13	11	48	35	-45	-23	10
23	c	2	-8	-29	-24	-16	40	10	-66	-52	-17	47	40	-39	-25	1
24	d	14	4	-50	-29	-10	72	32	-73	-48	-10	16	5	-79	-66	-33
25	d	26	15	-53	-19	7	45	30	-12	-1	15	53	43	-27	-15	12
26	d	25	6	-46	-28	-11	46	3	-68	-48	-23	46	32	-31	-18	4
27	d	17	-3	-38	-27	-16	60	15	-67	-41	-15	49	35	-39	-20	8
28	d	15	1	-58	-42	-21	45	21	-69	-54	-9	35	28	-32	-23	-2
29	d	18	3	-44	-26	-13	53	26	-57	-38	-6	52	32	-45	-31	2
	Avg.	18	3	-45	-29	-12	50	18	-61	-39	-11	46	33	-42	-25	4
	S.D	8.71	6.88	9.19	6.45	7.30	15.95	11.79	15.82	14.74	11.83	9.57	9.90	12.60	11.34	10.62
	Min.	2	-11	-65	-48	-28	20	-4.71	-83	-66.86	-37.29	16	4.8	-79	-65.6	-32.9
	Max.	47	16	-27	-18.5	7.71	79	46.7	-11	-1.4	15.57	62	51.5	-26	-12.8	22.8

Rep avg.- Repetition Average, OA- Overall Average
Negative values indicate end range of motion in ulnar deviation, extension, or supination.

Table 10-3: Total range of motion values by end range posture variable definition in degrees

		Radial /Ulnar deviation		Flexion / Extension		Pronation / Supination	
Subject	**Facility**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**	**Peak**	**Rep avg.**
1	a	68	40	90	62	83	58
2	a	49	25	93	54	106	64
3	a	72	33	107	60	102	67
4	a	61	37	135	78	102	70
5	a	69	39	118	55	87	62
6	a	59	32	101	60	79	60
7	a	55	33	127	49	94	59
8	a	57	41	122	63	82	62
9	a	88	38	124	70	73	44
10	a	72	39	138	71	72	45
11	b	55	28	91	56	91	52
12	b	54	35	102	58	103	72
13	b	70	39	127	54	74	50
14	b	77	37	131	57	106	63
15	b	68	35	49	34	77	49
16	c	37	18	84	40	80	65
17	c	53	30	133	68	93	53
18	c	63	30	118	50	85	46
19	c	58	27	132	52	94	61
20	c	44	21	85	39	94	55
21	c	85	38	141	61	105	58
22	c	62	28	105	43	93	57
23	c	31	16	106	63	86	66
24	d	64	33	145	80	95	70
25	d	79	34	57	32	80	58
26	d	71	34	114	50	77	50
27	d	55	24	127	56	88	55
28	d	73	42	114	74	67	51
29	d	62	29	110	64	97	63
	Avg.	62	32	111	57	88	58
	S.D	12.99	6.81	23.49	12.14	11.16	7.71
	Min.	31	16	49	31.5	67	44.2
	Max.	88	42.4	145	80	106	72

Table 10-4: Frequency variables recorded

Subject	**Facility**	**Duty cycle**	**Reps/min**	**Hrs/day**	**Reps/day**	**Total exposure (Hrs.)**
1	a	17%	23	4.5	6196	0.77
2	a	11%	15	4.5	4043	0.51
3	a	23%	30	5.42	9816	1.23
4	a	23%	31	4.5	8331	1.04
5	a	15%	20	3.96	4808	0.60
6	a	14%	19	3.6	4053	0.51
7	a	8%	11	0.45	292	0.04
8	a	10%	13	3.96	3072	0.38
9	a	16%	22	4.5	5852	0.73
10	a	14%	19	4.5	5201	0.65
11	b	17%	18	2.25	2404	0.39
12	b	19%	20	2.25	2653	0.43
13	b	33%	34	2.25	4540	0.73
14	b	28%	29	2.71	4708	0.76
15	b	20%	21	2.71	3441	0.55
16	c	21%	27	7.2	11816	1.53
17	c	26%	34	5.4	10921	1.42
18	c	17%	22	0.45	592	0.08
19	c	22%	28	4.5	7509	0.97
20	c	12%	15	3.06	2746	0.36
21	c	21%	27	2.25	3673	0.48
22	c	19%	25	0.45	665	0.09
23	c	11%	14	2.25	1869	0.24
24	d	21%	23	9	12205	1.90
25	d	23%	25	5	7380	1.15
26	d	29%	31	10	18403	2.86
27	d	31%	33	10	20000	3.11
28	d	20%	21	10	12619	1.96
29	d	25%	27	10	16155	2.51
	Avg.	20%	23.3	4.5	6757.4	1.0
	S.D	6%	6.47	2.90	5267.85	0.82
	Min.	8%	11	0.45	292	0.04
	Max.	33%	34	10	20000	3.11

Table 10-5: Average displacement, duration, velocity and acceleration values used to perform board turning

		Repetition 1		Repetition 2		Repetition 3		Repetition 4		Repetition 5		Avg. Velocity	Avg. Accel.
Subject	Facility	Displacement (deg)	Time (sec)	Displacement	Time	Displacement	Time	Displacement	Time	Displacement	Time	deg/sec	deg/sec^2
1	a	49	0.49	75	0.54	50	0.6	33	0.21	47	0.29	128.29	301.14
2	a	57	0.69	71	0.37	58	1.02	53	0.21	65	0.37	151.88	285.50
3	a	49	0.26	56	0.33	52	0.65	52	0.54	64	0.31	148.18	354.50
11	b	53	0.66	44	0.36	55	0.36	48	0.48	45	0.34	117.53	267.12
12	b	31	0.47	36	0.32	41	0.43	42	0.36	51	0.32	109.97	289.39
13	b	61	0.46	47	0.36	45	0.49	45	0.36	90	0.59	126.51	279.89
16	c	52	0.85	56	0.29	70	0.45	64	0.31	56	0.46	147.61	312.72
17	c	55	0.44	52	0.33	53	0.61	56	0.33	52	0.3	142.50	354.47
18	c	64	0.42	63	0.4	71	0.61	56	0.4	54	0.35	144.11	330.53
24	d	72	0.85	61	0.5	50	0.51	54	0.53	51	0.46	103.50	181.58
25	d	64	0.53	52	0.65	38	0.56	38	0.44	52	0.5	91.80	171.26
26	d	67	0.5	53	0.48	47	0.35	53	0.19	48	0.43	153.86	394.50

Table 10-6: Percentage of maximum voluntary contraction by muscle assessed and task component

		% MVC				Component values		Task average
Subject	**Facility**	**FCR**	**FCU**	**FDS**	**PT**	**Flex**	**Pronation**	**Overall average**
1	a	29%	27%	25%	65%	27%	65%	46%
2	a	38%	24%	6%	37%	23%	37%	30%
3	a	18%	20%	11%	45%	16%	45%	31%
4	a	54%	58%	12%	44%	41%	44%	43%
5	a	46%	27%	9%	66%	27%	66%	47%
6	a	14%	9%	8%	48%	10%	48%	29%
7	a	40%	45%	22%	52%	35%	52%	44%
8	a	29%	18%	23%	47%	23%	47%	35%
9	a	40%	6%	8%	57%	18%	57%	37%
10	a	54%	22%	13%	42%	30%	42%	36%
11	b	20%	22%	25%	8%	22%	8%	15%
12	b	10%	21%	6%	39%	12%	39%	26%
13	b	15%	17%	4%	23%	12%	23%	18%
14	b	29%	19%	14%	46%	21%	46%	33%
15	b	16%	19%	21%	23%	19%	23%	21%
16	c	38%	27%	18%	80%	28%	80%	54%
17	c	33%	38%	17%	46%	29%	46%	38%
18	c	34%	6%	19%	31%	20%	31%	25%
19	c	44%	34%	27%	58%	35%	58%	46%
20	c	38%	19%	12%	47%	23%	47%	35%
21	c	20%	24%	9%	49%	18%	49%	33%
22	c	50%	18%	16%	65%	28%	65%	47%
23	c	21%	22%	11%	41%	18%	41%	29%
24	d	7%	9%	3%	30%	6%	30%	18%
25	d	19%	17%	13%	59%	16%	59%	38%
26	d	22%	13%	13%	28%	16%	28%	22%
27	d	10%	11%	11%	20%	11%	20%	16%
28	d	19%	17%	17%	40%	18%	40%	29%
29	d	32%	11%	38%	64%	27%	64%	45%
	Avg.	29%	21%	15%	45%	22%	45%	33%
	S.D	13%	11%	8%	16%	8%	16%	11%
	Min.	7%	6%	3%	8%	6%	8%	15%
	Max.	54%	58%	38%	80%	41%	80%	54%

FCR – Flexor Carpi Radialis, FCU – Flexor Carpi Ulnaris, FDS- Flexor Digitorum Superficialis, PT- Pronator Teres

Table 10-7: Measures of exertion

		Electromyography		Psychophysical measures				
Subject	**Facility**	**Dynamic Force (N.)**	**% MVC**	**Borg avg.**	**Borg turn**	**Borg position**	**VAS str. demand**	**VAS overall demand**
1	a	96.1	46%	3.5	4	3	6.4	4.3
2	a	96.1	30%	3.5	4	3	3.9	3.8
3	a	96.1	31%	8	8	8	3.8	3.7
4	a	96.1	43%	6	7	5	6.3	5.1
5	a	96.1	47%	3.5	3	4	2.8	3.8
6	a	96.1	29%	3	3	3	7.8	7.9
7	a	96.1	44%	4	5	3	4.9	5.2
8	a	96.1	35%	5	5	5	5.4	5.1
9	a	96.1	37%	9	9	9	9.4	5.4
10	a	96.1	36%	4	5	3	2.4	3.3
11	b	88.9	15%	5	6	4	3.8	6.2
12	b	88.9	26%	5	4	6	6.8	7.4
13	b	88.9	18%	6	5	7	7	7.4
14	b	88.9	33%	5.5	6	5	4.9	5.8
15	b	88.9	21%	4	3	5	6.7	8
16	c	89.7	54%	6	7	5	8.8	9.1
17	c	89.7	38%	8.5	10	7	6.2	8.3
18	c	89.7	25%	5	4	6	6.9	7.2
19	c	89.7	46%	4.5	3	6	5.9	6.5
20	c	89.7	35%	7.5	5	10	5.7	8.3
21	c	89.7	33%	3	3	3	4.5	7.3
22	c	89.7	47%	7	7	7	6.5	6.9
23	c	89.7	29%	3	3	3	6.5	6.9
24	d	83.8	18%	6	6	6	6.1	7
25	d	83.8	38%	4.5	7	2	6.3	6.6
26	d	83.8	22%	4.5	4	5	6.3	7.9
27	d	83.8	16%	0.75	1	0.5	3.6	4.1
28	d	83.8	29%	4	5	3	6.1	5.2
29	d	83.8	45%	5	5	5	6.6	6.4
	Avg.	90.6	33%	5	5	5	6	6
	S.D	4.65	11%	1.83	2.02	2.14	1.63	1.61
	Min.	83.8	15%	1	1	1	2	3
	Max.	96.1	54%	9	10	10	9	9

Figure 10-1: Trim saw operator primary task sequence

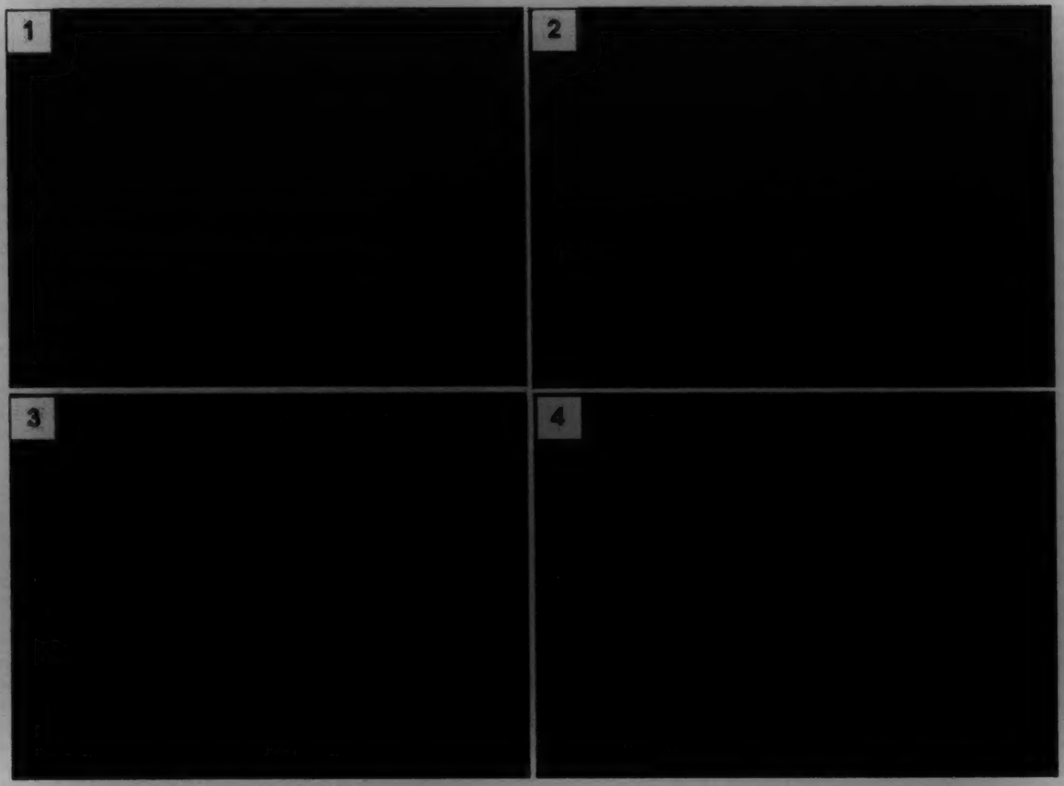
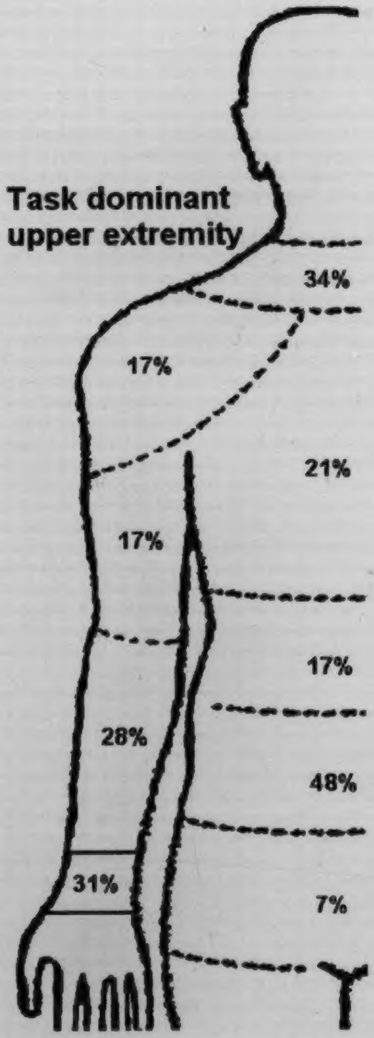


Figure 10-2: Job simulated exertion set-up

Figure 10-3: Body part discomfort ratings


Task dominant
upper extremity
34%
17%
21%
17%
17%
28%
48%
31%
7%

10.8 References

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Phase 2 Summary: Collection of physical exposure data.

Observational ergonomic risk assessments consider the physical exposures required to perform industrial tasks in deriving a measure of risk. Valid comparison of risk output between methods is dependent upon an accurate and representative physical exposure assessment. As described in chapters 7-10 all studies presently published which compare the risk output of several methods are based on physical exposure measurements performed via observation. A large body of evidence is now present which has established the significant measurement error resulting from exposure assessment via observation. For the above reason quantified measurement tools were used in phase 2 of the research project to collect exposure information. Figures P2-1 and P2-2 provide examples of the output obtained from the quantified exposure assessment tools used. No studies prior to the studies which comprise chapters 7-10 have quantified the physical exposures required to perform high risk jobs based on definitions appropriate for use in ergonomic risk assessments.

Several specific comparisons were of interest given the collected quantified exposure information. First, it was of interest to describe the physical exposures required to perform four high risk sawmill occupations. Table P2-1 describes the physical exposures required to perform the primary job tasks of the four occupations examined. The collection of quantified exposure information was needed to allow valid comparisons of ergonomic risk output in phase three of the research project. Given the quantified nature of the exposure information available to the researchers it was also possible to examine the comparability of multiple definitions of the posture and exertion variables used interchangeably by practitioners in the application of risk assessment methods. With regard to the comparison of measures of exertion, collected via quantified and psychophysical means, no correlation was observed between methods in any one occupation. With regard to the comparability of posture variable definitions examined significantly different ranges of motion (ROM) were derived dependent upon end point used in all occupations. Table P2-2 describes the degree of statistical significance and percentage ROM reduction by occupation and plane of motion when repetition average posture values were substituted for peak values. The finding of meaningful differences suggested comparisons of ergonomic risk assessment methods performed in the third phase of the project should include comparisons within methods calculated with different variable combinations. In contrast to previously published work which has compared the physical exposures (and resulting ergonomic risk assessment scores) across a number of jobs of varying degrees of risk the studies in phase two and three have focused on the comparison of physical exposures (and resulting ergonomic risk assessment scores) within high risk jobs only. The collection of physical exposure information in a sample of industrial workers which closely represents the population of workers allowed the examinations of within occupation exposure variability not previously described. Table P2-3 describes the coefficient of variation values observed between workers by occupation and exposure variable. The meaningful variability between workers observed suggests that, contrary to accepted practice, more then one worker must be assessed to obtain exposure assessment scores representative of an occupation. These findings suggest that the effect of variation in exposure between workers within occupations must be examined in the third phase of the thesis project.

Table P2-1: Physical exposures required to perform the primary task by occupation.

		Board edger	Lumber grader	Saw filer	Trim saw operator
Subject characteristics	Age (yrs.)	Mean 33 S.D 6.3	Mean 29.9-37.1	Mean 44 S.D 9.5	Mean 31 S.D 8.2
	Height (cm.)	Mean 178 S.D 6.1	Mean 174.4 S.D 183.8	Mean 178 S.D 7.5	Mean 180 S.D 6.7
	Weight (kg.)	Mean 88.7 S.D 13.4	Mean 81.6 kg S.D 14.7	Mean 86.1 S.D 14.8	Mean 88.1 S.D 12.9
	Experience years	Mean 3.3 S.D 2.1	Mean 4.4 S.D 4.9	Mean 11.5 S.D 6.8	Mean 3.5 S.D 4.1
Force / Exertion	%MVC	Mean 33 S.D 8	Mean 9 S.D 4	Mean 10 S.D 3	Mean 33 S.D 11 S.D
	Dynamic force (N)	Mean 96.4 S.D 1.7	Mean 38.5 S.D 1.77	Mean 11.8 S.D.11	Mean 90.6 4.65
	Borg avg.	Mean 5.5 S.D 1.7			Mean 5.0 S.D 1.8
	Borg turn / hammer	Mean 5.4 S.D 1.8	Mean 4.7 S.D 1.6	Mean 3.7 S.D 1.9	Mean 5.1 S.D 2.02
	Borg position	Mean 5.5 S.D 2.0			Mean 4.9 S.D 2.14
Posture (repetition average):	Radial range (degrees)	Mean 4 S.D. 4	Mean 3 S.D 8.6	Mean -15 S.D 8	Mean 3 S.D 6.8
	Ulnar range (degrees)	Mean 29 S.D. 6	Mean 18 S.D 11	Mean 25 S.D 7.5	Mean 29 S.D 6.45
	Flexion range (degrees)	Mean 18 S.D. 10	Mean 1 S.D 11	Mean 6 S.D 9	Mean 18 S.D 11.8
	Extension range (degrees)	Mean 34 S.D 11	Mean 43 S.D 14	Mean 13 S.D 11	Mean 39 S.D 14.7
	Supination range (degrees)	Mean 23 S.D 10	Mean 19 S.D 8	Mean 11 S.D 12	Mean 25 S.D 11.3
	Pronation range (degrees)	Mean 28 S.D 12	Mean 33 S.D 12	Mean 17 S.D 10	Mean 33 S.D 9.9
Frequency	Duty cycle	Mean 16 S.D 8	Mean 38 S.D 8	Mean 18 S.D 7	Mean 20 S.D 6
	Reps/min	Mean 16 S.D 7	Mean 34 S.D 6	Mean 31.7 S.D 13.5	Mean 23 S.D 6.47
	Hrs/day	Mean 6 S.D 2	Mean 5.7 S.D 2.1	Mean 3.9 S.D 2.4	Mean 4.5 S.D 2.9
	Reps/day	Mean 6215 S.D 4437	Mean 11743.6 S.D 4754	Mean 7972 S.D 8505	Mean 6757 S.D 5267
	Total exp	Mean 1.04 S.D 0.76	Mean 2.2 S.D 0.96	Mean 0.71 S.D 0.64	1.0 S.D 0.82

Table P2-2: Degree of statistically significant difference and percentage reduction in ROM when repetition average posture values are substituted for peak posture values by occupation.

	Board edger	**Lumber grader**	**Saw filer**	**Trim saw operator**
Radial/ulnar	$p<.001$ (↓56%)	$p<.001$ (↓46%)	$p<.001$ (↓81%)	$p<.05$ (↓51%)
Flexion/extension	$p<.001$ (↓52%)	$p<.001$ (↓52%)	$p<.001$ (↓80%)	$p<.05$ (↓52%)
Pronation/supination	$p<.001$ (↓62%)	$p<.001$ (↓69%)	$p<.001$ (↓92%)	$p<.05$ (↓66%)

Table P2-3: Coefficient of variation values observed within occupations by exposure variable.

		Board edger	**Lumber grader**	**Saw filer**	**Trim saw operator**
Force / Exertion	**%MVC**	26%	45%	35%	32%
	Dynamic force (N)	2%	5%	1%	5%
	Borg	31%	35%	53%	37%
	VAS str. demand	30%	37%	30%	28%
	VAS overall	33%	30%	23%	26%
Range of Motion: All subjects grouped	**Radial/ulnar**	15%	28%	50%	21%
	Flexion/extension	17%	24%	33%	21%
	Pronation/supination	15%	27%	58%	13%
Frequency	**Duty cycle**	49%	21%	40%	32%
	Reps/min	48%	18%	43%	28%
	Hrs/day	40%	38%	61%	64%
	Reps/day	71%	40%	107%	78%
	Total exp	73%	44%	90%	85%

Figure P2-1: Example of electromyography output.

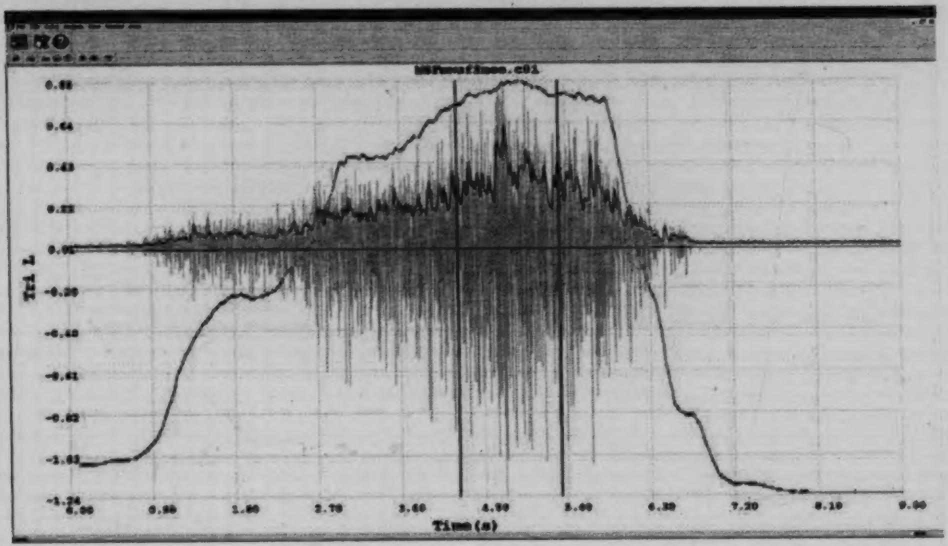
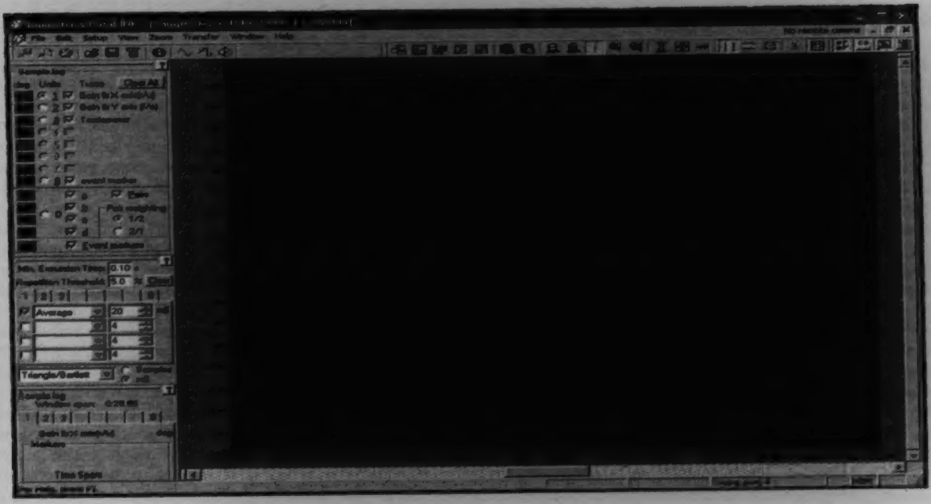

0.85
0.64
0.43
0.22
0.01
-0.20
-0.40
-0.61
-0.82
-1.03
-1.24
Tri L
0.00
0.90
1.80
2.70
3.60
4.50
5.40
6.30
7.20
8.10
9.00
Time (s)

Figure P2-2: Example of electrogoniometer output.


File
Edit
Setup
View
Zoom
Transfer
Window
Help
Clear All
event marker
Event markers
Clear
Average
Triangle/Bartlett
Markers
Time Span

Min. Excursion Time 0.10 s

Repetition Threshold 5.0 %

Chapter 11 – Comparison of ergonomic risk assessments in a repetitive sawmill occupation: board edger operator

A version of this chapter was submitted for publication in the journal Ergonomics in July 2006.

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11.1 Introduction

In 2003 a comprehensive Workers Compensation Board data set was reviewed to identify and describe injury and illness trends in the Sawmill industry of Alberta, Canada (Jones et al. 2004a). During the period reviewed musculoskeletal injuries accounted for 33% of the total cost and 38% of total time lost due to claim, more than any other injury category. Musculoskeletal injuries (MSIs) in the upper extremity resulted in 1698 Workers Compensation Board Claims, more than any other body region. Given the impact of MSIs on the sawmill industry, prevention has become a primary focus of health and safety programs. The role of physical exposures in the causation of MSIs has been established but specific cause effect relationships remain elusive (NIOSH 1997). Due to the absence of specific cause-effect relationships the practice of industrial MSI prevention relies heavily on guidelines established by health and safety organizations internationally and applied through peer-reviewed ergonomic risk assessments. Identifying the peer-reviewed risk assessment most capable of identifying jobs and exposures of concern for intervention is an important step in developing an effective industrial prevention program.

Little agreement currently exists between authors as to the best method of determining risk of MSI (Jones and Kumar 2004b). A key issue affecting our ability to examine the properties of ergonomic risk assessments in the past has been the accuracy and reliability of physical exposure information collected via observation (Lowe 2004).

Reliable measurement techniques capable of quantifying physical exposures are now available and thus an examination of the properties of risk assessments may proceed. Very few studies have been performed which compare the results of multiple risk assessment methodologies to gain insight into the properties of the assessments (Drinkaus et al. 2003, Bao et al. 2006). The recording of physical exposures in two facilities with differing historical rates of injury allows the sensitivity of the assessments to differing levels of risk to be examined. No studies could be located which sought to determine if risk assessments could differentiate between facilities with differing incidence rates in a repetitive job. Quantification of physical exposures allows the work site evaluator apply several definitions to the exposure variables considered by the risk assessment models. The ability to apply multiple definitions makes an examination of the effect of exposure variable definition on risk assessment output necessary. No studies could be located which seek to examine the effect of multiple variable definitions on risk assessment output. For these reasons this study sought to: 1) compare the results of five commonly used ergonomic risk assessments 2) examine the ability of the risk assessments to detect differences in level of risk between facilities 3) examine the effect of different posture and exertion variable definitions on risk assessment component and output scores. The risk assessment methods compared in this study are the: rapid upper limb assessment (RULA), rapid entire body assessment (REBA), the quantified version of the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV), the Strain Index (SI), and the Concise Exposure Index (OCRA) (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005). Risk assessment methods used in this study were selected based on semi objective criteria. All risk assessment methods considered for inclusion in this study generate an output which may be used to prioritize jobs and problem exposures for intervention. There is presently little literature examining the psychometric properties of ergonomic risk assessments individually. Similarly there is a paucity of literature examining the comparability of multiple risk assessment methods. Due to the lack of literature examining ergonomic risk assessment methods selection of methods to be compared in these studies based on an objective decision matrix was not possible. Methods used in these studies were selected based upon their common use in industrial MSI prevention initiatives. Risk indexes in this study refer to the risk assessments' raw score output before that score is grouped and interpreted. Risk levels refer to the groupings of risk index scores which are interpreted into action levels etc. by the authors.

The board edger position was selected for evaluation, given the high number of upper extremity musculoskeletal injuries recorded in the 6 years of the review. Average annual incidence of recordable musculoskeletal events in the board edger operator ranged from 0.22 (facility A) to 1.33 (facility B) per person year worked in the period examined.

11.2 Methods

11.2.1 Occupation identification

Deriving incidence rates for the board edger position using compensation information was not possible given information describing the complete work force was not available (Jones et al. 2004a). For this reason the occupational health records of two sawmill facilities were consulted to determine which production positions were commonly associated with injuries of musculoskeletal nature to the upper extremity and the board edger position was selected.

11.2.2 Task description

The board edger position is a repetitive job responsible for sorting boards cut in rough depth dimension immediately after logs have been cut to square dimension and divided into multiple boards. Sorting of the boards involves frequent 'flipping' (turning about the long axis) of boards to position the board with the round side (cant) up for further processing (figure 11-1). Turning boards is the primary task of the board edger however, he/she may also be required to push, pull and lift boards to cause them to fall to conveyors below. Width and length of boards at this early stage in production vary by dimension of the log processed.

11.2.3 Subject selection

Male and female workers presently performing the board edger position between the ages of 18 and 65 were recruited at two sawmill facilities. Subjects were excluded from the study if they reported; injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. No female workers were present at the two facilities examined. 16 male subjects volunteered to take part in the study out of the population of 16 (100% participation rate). Complete data sets enabling analysis were collected for 14 of 16 subjects.

11.2.5 Data collection

11.2.5.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to turn boards as described in part 1 of this series (Jones and Kumar, submitted to Ergonomics 2006). *11.2.5.1.1 Posture.* Postures required to perform the board edger operator position were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (turning boards). The repetition average posture was defined by randomly selecting 10 repetitions (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample. In the cases where body regions other than the forearm and wrist are considered (REBA, RULA, OCRA) only the postures of the forearm and wrist vary from peak excursions in the posture variable comparisons. *11.2.6.2.2 Duty cycle.* The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

11.2.6.2.3 Frequency. Repetitions performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees (setting observed to best differentiate between repetitions of primary board turn task) at the proximal radio-ulnar joint (pronation/supination). Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used.

11.2.5.2 Exertion data acquisition

11.2.5.2.1 Percentage of maximum voluntary contraction. Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction and job simulated exertions as described in part one of this series (Jones and Kumar, In press Ergonomics 2006). The average value resulting from the muscles assessed during the job simulated flexion trial and the job simulated pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the task components (flexion and pronation). The task components were then averaged to derive %MVC required to perform the primary (board turn) task.

11.2.5.2.2 Psychophysical measure of exertion. Following data collection during job performance workers were asked whether; "during the cycle were there job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the exertion required to perform the actions from one to ten using the Borg CR-10 scale (Borg 1982). Borg ratings were then averaged and used in the ACGIH TLV, SI and OCRA assessments.

11.2.5.2.3 Dynamic force applied. Dynamic forces required were used as the exertion variable in the RULA and REBA methods. Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration recorded.

11.2.6 Data Analysis

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Mann-Whitney U test (alpha level 0.05) was used to determine if significant differences existed between facilities on risk assessment output scores (component, combined component, risk index, risk level). The Wilcoxin W test (alpha level of .05) was used to test whether significant differences existed between risk assessment scores derived using alternate posture and exertion variable definitions.

11.2.7 Risk assessment methods

Risk indexes were calculated according to the primary literature describing their application (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005).

11.3 Results

11.3.1 Incidence of upper extremity musculoskeletal injury

Alberta Workers Compensation Board data indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the board edger operator position. Incidence rates in the board edger position calculated based on person year estimates from the two facilities averaged 0.22 and 1.33 recordable musculoskeletal upper extremity incidents per person year in the period examined.

11.3.2 Subject characteristics

The average age of subjects was 33 (S.D. 6.3), average height of subjects was 178 cm (S.D. 6.1 cm), and average weight of subjects was 88.7 kg. (S.D. 13.4 kg.). Average work experience at the board edger position at time of assessment was 3.3 years (S.D. 2.1 yrs.).

11.3.6 Risk assessment methods

Mean risk level assigned by risk assessment method as a percentage of maximum is illustrated for the reader in figure 11-2.

11.3.6.1 RULA

11.3.6.1.1 Between facility comparisons: No variation was observed between subjects or between facilities in either RULA index or risk level scores (risk index 7, risk level 4). The lack of variation in RULA risk index and risk level scores indicates that the RULA assessment was not sensitive to differing levels of risk between facilities. Certain RULA component scores were able to differentiate between facilities however. RULA posture scores specific to the neck, trunk, legs and upper arm (shoulder) were significantly different between facilities ($p<.05$). In addition combined upper extremity posture score, combined trunk/neck/leg score and the integrated trunk score (RULA score D) were significantly different between facilities ($p<.05$). These results indicate that components of the RULA methodology are sensitive to inter-facility differences however final risk output is not. Table 11-1 describes the RULA scores calculated with dynamic force and peak postures.

11.3.6.1.2 Within methodology comparisons: Effect of varying wrist and forearm posture variable definition: Substituting overall average posture for peak or repetition average postures resulted in significantly different combined upper extremity posture scores ($p<.01$) but had no effect on risk index or risk level. Substitution of overall average scores for peak postures reduced combined upper extremity posture scores in 12 of 14 subjects by an average of 18%. Substituting overall average posture scores for repetition average scores reduced scores in 10 of 14 subjects by an average of 19%. Upper extremity component scores were sensitive to changing posture variable definition but did not impact the final risk output scores. These results indicate it is likely that had all body segments considered by the RULA methodology been measured by quantified means (allowing multiple definitions of posture to be applied to all regions) final output scores would have been influenced by posture definition chosen. Table 11-2 describes the effect of posture variable definition on combined upper extremity posture and risk index score.

11.3.6.2. REBA

11.3.6.2.1 Between facility comparisons: REBA risk index scores were significantly different between the facilities examined ($p<.01$) indicating the REBA assessment was sensitive to differing levels of risk between facilities. REBA risk level scores did not differ significantly between facilities examined. REBA component scores able to differentiate between facilities were the posture scores specific to the trunk, legs, upper arm, and the REBA activity score ($p<.05$). Combined scores able to differentiate between facilities included the combined upper extremity posture score, combined trunk/neck/leg posture score, the integrated upper extremity score (score A), the integrated trunk/neck/leg score (score B) and combined body segment score (score C) ($p<.05$). Table 11-3 describes the REBA scores calculated based on dynamic force and peak postures.

11.3.6.2.2 Within methodology comparisons: Effect of varying wrist and forearm posture variable definition: Substituting overall average postures for peak or repetition average postures resulted in significantly different upper extremity posture scores ($p<.01$) but had no effect on risk index and risk level scores. Substituting repetition average postures for peak postures resulted in no change in combined upper extremity posture scores. Combined upper extremity scores were reduced in 10 of 14 subjects by an average of 15% when overall average postures were substituted for peak or repetition average postures. Similar to the RULA assessment, REBA results indicate it is likely that had all body segments considered by the REBA methodology been measured by quantified means (allowing multiple definitions of posture to be applied) final output scores would have been influenced by posture definition chosen. Table 11-4 describes the impact of posture variable on combined upper extremity posture score and risk index.

11.3.6.3 ACGIH TLV for mono-task hand work

11.3.6.3.1 Between facility comparisons: No risk index is generated by the ACGIH-TLV for mono-task hand work. Risk level scores were not significantly different between facilities when calculated with either the %MVC exertion variable or the Borg exertion variable. The ACGIH TLV hand activity level component score did vary significantly by facility (p<.01).

3.6.3.2 Within methodology comparisons: Effect of varying exertion variable definition: ACGIH TLV exertion component scores and risk level scores calculated with the %MVC exertion criterion were significantly different than those calculated with the Borg criterion (p<.01). Substituting the Borg exertion variable for the %MVC exertion variable elevated scores by an average of 95% in 11 of 14 subjects. Final risk level output derived using the %MVC exertion variable was not comparable to those derived using the Borg exertion variable in 11 of 14 (79%) subjects. Table 11-5 describes the ACGIH TLV scores calculated based on %MVC and Borg exertion variables.

11.3.6.4 Strain index

11.3.6.4.1 Between facility comparisons: Strain index risk index scores were significantly different between facilities assessed (p<.05). Strain index risk level scores did not differentiate between facilities assessed. Strain index component scores able to differentiate between facilities assessed included the speed of work, duration per day and hand wrist posture by all posture variable definitions (p<.05). Our results indicate the strain index methodology was sensitive to differing exposures between facilities assessed and that these differences were reflected in the risk index output. Table 11-6 describes the SI scores calculated with the %MVC exertion variable and peak postures.

3.6.4.2 Within methodology comparisons: Effect of varying hand/wrist posture variable definition: Substituting repetition average for peak postures, overall average for peak postures and overall average for repetition average postures resulted in significantly different posture multiplier values and risk index scores (p<.01). The effect of substituting repetition average postures for peak postures was an average risk index score reduction of 35% in 11 of 14subjects. The effect of substituting overall average postures for peak postures was an average risk index score decrease of 55% across all subjects. Lastly the effect of substituting overall average postures for repetition average postures was an average decrease in risk index scores of 39% across all subjects. Our results indicate that calculation of strain index risk index scores based on the 3 posture variable definitions examined resulted in significantly different risk indexes. Table 11-7 describes the impact of posture variable definition on posture component score and risk index.

3.6.4.2 Within methodology comparisons: Effect of varying exertion variable definition: Substitution of the Borg exertion variable for the %MVC variable resulted in significantly different intensity component scores and risk index scores (p<.01). Substituting the Borg exertion variable for the %MVC variable resulted in an increased risk index score by an average of 129% in 8 of 14 subjects and a decreased risk index score by 50% in 1 of 14 subjects. Our results indicate that-risk index scores based on the Borg exertion variable definition not comparable to those generated using the %MVC exertion variable in 9 of 14 (64%) of subjects. Table 11-8 describes the impact of exertion variable definition on intensity component score and risk index.

11.3.6.5 OCRA

11.3.6.5.1 Between facility comparisons: OCRA risk index and risk level scores were not significantly different between facilities assessed. The OCRA additional items factor, duration of repetitive task, and total repetitions component scores were sensitive to inter facility differences (p<.01). Our results indicate the risk output of the OCRA assessment was not sensitive to differences in risk of injury between facilities. Table 11-9 describes the OCRA scores calculated with the %MVC exertion variable and peak postures.

11.3.6.5.2 Within methodology comparisons: Effect of varying hand/wrist posture variable definition: Substituting repetition average or overall average for peak postures resulted in significantly different posture multiplier and risk index scores (p<.01) but had no effect on risk level. Substituting repetition average posture for peak posture reduced risk index scores by an average of 23% in 12 of 14 subjects. Substituting overall average postures for peak postures reduced risk index scores by an average of 24% in 13 of 14 subjects. Changing posture variable definitions resulted in significantly different risk index scores in 93% of subjects. Table 11-10 describes the impact of posture variable definition on posture component score and risk index.

11.3.6.5.2 Within methodology comparisons: Effect of varying exertion variable definition: Substituting the Borg exertion variable for the %MVC variable resulted in significantly different component scores (p<.01), risk index scores (p<.0001) and risk levels (p<.001). Substitution of the Borg exertion variable for the %MVC exertion variable increased risk index scores by an average of 88% in 11 of 14 subjects and reduced risk index scores by an average of 64% in 2 of 14 subjects. Substituting the Borg exertion variable for the %MVC variable resulted in significantly different OCRA risk index scores in 13 of 14 (93%) of subjects. Table 11-11 describes the impact of exertion variable definition on exertion component score and risk index.

11.4 Discussion

11.4.1 Sensitivity of risk assessment methods to facility and worker assessed

Mean risk level assigned by all the methods examined, with the exception of the ACGIH TLV calculated with %MVC, indicates that there is risk of musculoskeletal injury associated with performance of the board edger position. While a finding of job risk based on the risk level score is sufficient to determine if a job common to an industry is "at-risk" it is insufficient to identify site specific problem exposures and direct site specific interventions. The two facilities examined in this study report seemingly different incidence rates (facility A- 0.22, facility B- 1.33) yet no differences were observed in risk level scores in any methodology examined. If the difference in physical exposures between the facilities are responsible for the greater than 6 fold increase in incidence, the problem exposure(s) should be detected by the risk assessment methodologies. Part 1 of this series identified significant differences between facilities assessed in all frequency variables examined. The total exposure of workers in facility B was significantly higher than facility A.

The calculation of the risk methodologies using quantified physical demands data has demonstrated the sensitivity of the risk index scores of the methods to individual worker technique. Sensitivity to worker technique confirms that a number of worker assessments are required to derive a representative risk index score for the facility. Should representative risk index score for a job specific to a facility be derived it may be possible to differentiate between facilities known to have meaningfully different incidence rates (such as the case with the two facilities examined in this study). Significant differences between facilities were observed in component scores, combined scores and risk index scores in all methodologies indicating that at least some aspect of the methodologies were sensitive to differences between facilities. Only through interpretation of the component and risk index scores does the work site evaluator gain insight into the problem exposures. The ACGIH TLV, SI and OCRA procedures detected significant differences between the facilities in frequency and duration component scores. Only in the cases of the SI and REBA assessments did these exposures result in integrated risk output (risk index scores) which differentiated between facilities however. This finding is important as it suggests model of MSI injury causation upon which the assessment derives a risk output may be accurately describing the relative role of the variables in MSI causation. If the correct relative role of the exertion variables has been assigned industrial prevention efforts which use the methods to direct intervention stand a greater chance of success.

11.4.2 Maximizing risk assessment sensitivity

Interpretation of component and risk index scores based on an accurate record of physical exposures is necessary to direct site specific prevention efforts. Maximizing sensitivity of the methodologies to inter-subject variability stands to increase the ability of ergonomic risk assessments to identify problem exposures and direct prevention efforts. Inter-subject variability on component, combined component and output scores is affected by the resolution of the assessment's components (number of scoring categories) and the model structure. Greater inter-subject variability in intensity scores can be expected in the ACGIH TLV and OCRA exertion component scores (10 categories) for example than the REBA and RULA exertion component scores (4 categories). The availability of tools capable of accurately and reliably quantifying physical demands negates the previously imposed necessity of broad exposure categories to reduce measurement error due to observation. Increased resolution in exposures categories can now be pursued as accurate quantified measurements of exposure are possible. The structure of the model upon which the risk assessment is based may also increase or decrease the sensitivity of the risk assessment method. Multiplicative methods such as the SI and OCRA methods generate interval level output scores. The RULA, REBA and ACGIH TLV methods function to progressively reduce the numerical power of final output by limiting possible combined variable and risk output scores to the ordinal level through use of tabular "look up" methods. The multiplicative structure of the OCRA and SI therefore allows considerably greater variability among subjects than the tabular "look-up" methods of the RULA, REBA and ACGIH methods. Maximizing the inter-subject variability in risk output measures stands to increase the ability of the risk assessment output to identify problem exposures.

11.4.2 Effect of varying of posture and exertion variable definition on risk output

At a minimum, components of the risk methodologies examined have been shown to be sensitive to inter-worker variability and in some cases inter facility variability. Use of quantified tools to collect physical exposure information affords the examiner the ability to apply multiple definitions of the posture and exertion variable. In each of the methodologies examined the posture or force variable definition used has been shown to result in significantly different component, combined component and/or risk output scores. Posture variable definition resulted in significantly different scores in every risk assessment methodology considering posture, influencing scores by a much as 55%. Exertion variable definition resulted in significant different risk assessment scores in all methods in which either definition may be applied, affecting scores in both directions (may reduce or increase scores) by as much as 129%. The primary literature describing the ACGIH TLV, SI, and OCRA methods suggests either the %MVC required to perform the job or a Borg rating of exertion may be used to define the exertion variable (Moore et al. 1995, Colombini 1998, University of Michigan 2005). Our results indicate the Borg exertion variable and the %MVC exertion variable, as they have been defined in this study, are not equivalent.

Further studies exploring the effects of posture and exertion variable are needed to provide insight as to the best variable definition to be used. In order to examine the predictive validity of risk assessment methods a greater amount of detail is required from occupational health surveillance systems. Studies seeking to identify problem exposures in at-risk jobs must be based on representative quantified physical exposures and draw on a standardized surveillance system which accurately records the industry, occupation, severity of injury, and exposure to the job. While this study has recorded quantified demands in a representative sample (88% of population) neither the occupational health records of the facilities examined nor Workers Compensation Board dataset provides sufficient information to examine the association between risk assessment scores and incidence of injury. With respect to the site specific surveillance systems the unique nature of the systems limits our ability to draw meaningful conclusions based on the grouped data. In the case of the Workers Compensation Board dataset no information is collected on the total number of workers performing the board edger position and the resolution of the occupation performed data fields is not sufficient to identify specific production positions. Our ability to delve further into the relationship between the exposures and the incidence of injury is therefore limited to the suggestive analysis performed. In this case it seems total exposure to the job has resulted in a higher incidence of musculoskeletal injury in facility B and that the integrative models of MSI causation used by the SI and REBA assessments were best able to identify this difference.

11.5 Conclusion

In light of the foregoing data and discussion of the risk assessment methods the following general picture can be drawn: All the methodologies examined (with the exception of the ACGIH TLV) have identified a level of risk in the repetitive board edger position. Risk assessment methodologies which consider multiple body regions, broad exposure groupings, and output ordinal risk index scores were less sensitive to differences in worker technique than methods requiring increased resolution to assign component scores and use multiplicative model structure. All methodologies examined were significantly impacted by posture and exertion variables chosen. Future studies examining the association of risk methodology model output and incidence of MSI are needed which draw on representative quantified physical demands and detailed incidence information to improve our understanding of how integrated physical exposures result in MSI. Evidence based risk indices with rigorous epidemiological validation is essential to increase the level of scientific sophistication. As our understanding of MSI causation improves the utility of ergonomic risk assessments to direct effective prevention will improve.

11.6 Acknowledgement

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Table 11-1: RULA scores calculated with peak postures

		Component scores							Combined component scores								Risk output scores	
		Posture Trunk/Neck/Legs			Posture Upper extremity				Trunk/Neck/Legs				Upper extremity				Risk index	Risk level
Subject	Facility	Neck	Trunk	Legs	Upper arm	Lower arm	Wrist	Wrist twist	Posture	Muscle	Force	Score D	Posture	Muscle	Force	Score C	Grande score	Risk Level
1	a	5	3	2	4	3	4	1	8	1	3	12	6	1	3	10	7	4
2	a	5	2	1	3	3	4	1	7	1	3	11	5	1	3	9	7	4
3	a	2	4	1	4	3	4	1	5	1	3	9	6	1	3	10	7	4
4	a	3	4	2	4	3	4	1	6	1	3	10	6	1	3	10	7	4
5	a	2	1	1	3	2	4	1	2	1	3	6	5	1	3	9	7	4
6	a	2	4	1	4	2	4	1	5	1	3	9	5	1	3	9	7	4
7	b	5	4	2	5	3	4	2	8	1	3	12	8	1	3	12	7	4
8	b	4	5	2	4	3	4	2	7	1	3	11	6	1	3	10	7	4
9	b	6	5	2	4	3	4	1	9	1	3	13	6	1	3	10	7	4
10	b	5	5	2	4	3	4	2	8	1	3	12	6	1	3	10	7	4
11	b	6	4	2	4	3	4	1	9	1	3	13	6	1	3	10	7	4
12	b	3	3	2	5	2	4	1	5	1	3	9	7	1	3	11	7	4
13	b	5	5	2	6	3	4	2	8	1	3	12	9	1	3	13	7	4
14	b	5	5	2	5	3	4	2	8	1	3	12	8	1	3	12	7	4
	Avg.	4	4	2	4	3	4	1	7	1	3	11	6	1	3	10	7	4
	SD.	1.5	1.2	0.5	0.8	0.4	0.0	0.5	2.0	0.0	0.0	2.0	1.2	0.0	0.0	1.2	0	0
	Min.	2	1	1	3	2	4	1	2	1	3	6	5	1	3	9	7	4
	Max.	6	5	2	6	3	4	2	9	1	3	13	9	1	3	13	7	4

Table11- 2: RULA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	6	6	4	7	7	7
2	a	5	5	4	7	7	7
3	a	6	6	5	7	7	7
4	a	6	6	5	7	7	7
5	a	5	5	4	7	7	7
6	a	5	5	4	7	7	7
7	b	8	7	7	7	7	7
8	b	6	6	6	7	7	7
9	b	6	6	5	7	7	7
10	b	6	6	5	7	7	7
11	b	6	6	5	7	7	7
12	b	7	7	6	7	7	7
13	b	9	9	9	7	7	7
14	b	8	7	7	7	7	7
	Avg.	6.4	6.2	5.4	7.0	7.0	7.0
	S.D.	1.22	1.05	1.45	0.0	0.0	0.0
	Min.	5.0	5.0	4.0	7.0	7.0	7.0
	Max.	9.0	9.0	9.0	7.0	7.0	7.0

Rep. avg. – Repetition average posture

Table 11-3: REBA index calculated with peak postures

Component scores								Combined component scores								Risk output scores	
		Trunk/Neck/Legs			Upper extremity			Trunk/Neck/Legs			Upper extremity			Multiple body part		Risk index	Risk level
Subject	Facility	Trunk	Neck	Legs	Upper arm	Lower arm	Wrist	Posture total	Force	Score A	Posture Total	Grip	Score B	Score C	Activity score	Grand score	Risk Level
1	a	3	3	2	4	2	3	6	1	7	7	1	8	10	1	11	4
2	a	2	3	1	3	2	3	4	1	5	5	1	6	7	1	8	3
3	a	4	2	1	4	2	3	5	2	7	7	1	8	10	2	12	4
4	a	4	2	2	4	2	3	6	2	8	7	1	8	10	1	11	4
5	a	1	2	1	3	1	3	1	1	2	5	1	6	4	1	5	2
6	a	4	2	1	4	2	3	5	2	7	7	1	8	10	2	12	4
7	b	4	1	2	5	2	3	5	2	7	8	1	9	10	2	12	4
8	b	5	2	2	4	2	3	7	2	9	7	1	8	11	2	13	4
9	b	5	3	2	4	2	3	8	2	10	7	1	8	12	2	14	4
10	b	5	3	2	4	2	3	8	2	10	7	1	8	12	2	14	4
11	b	4	3	2	4	2	3	7	2	9	7	1	8	11	2	13	4
12	b	3	2	2	5	1	3	5	2	7	8	1	9	10	2	12	4
13	b	5	3	2	6	2	3	8	2	10	9	1	10	12	2	14	4
14	b	5	3	2	5	2	3	8	2	10	8	1	9	12	2	14	4
	Avg.	3.9	2.4	1.7	4.2	1.9	3.0	5.9	1.8	7.7	7.1	1.0	8.1	10.1	1.7	11.8	3.8
	S.D.	1.23	0.65	0.47	0.80	0.36	0	1.98	0.43	2.27	1.07	0	1.07	2.20	0.47	2.55	0.58
	Min.	1.0	1.0	1.0	3.0	1.0	3.0	1.0	1.0	2.0	5.0	1.0	6.0	4.0	1.0	5.0	2.0
	Max.	5.0	3.0	2.0	6.0	2.0	3.0	8.0	2.0	10.0	9.0	1.0	10.0	12.0	2.0	14.0	4.0

Table 11-4: REBA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	7	7	6	11	11	11
2	a	5	5	5	8	8	8
3	a	7	7	6	12	12	12
4	a	7	7	6	11	11	11
5	a	5	5	4	5	5	5
6	a	7	7	6	12	12	12
7	b	8	8	8	12	12	12
8	b	7	7	7	13	13	13
9	b	7	7	6	14	14	14
10	b	7	7	6	14	14	14
11	b	7	7	6	13	13	13
12	b	8	8	7	12	12	12
13	b	9	9	9	14	14	14
14	b	8	8	8	14	14	14
	Avg.	7.1	7.1	6.4	11.8	11.8	11.8
	S.D.	1.07	1.07	1.28	2.55	2.55	2.55
	Min.	5.0	5.0	4.0	5.0	5.0	5.0
	Max.	9.0	9.0	9.0	14.0	14.0	14.0

Rep. avg. – Repetition average posture

Table 11-5: ACGIH TLV scores calculated with %MVC and Borg exertion variables

		Component scores			Risk level	Risk level
Subject	Facility	% MVC exertion score	Borg exertion score	Hand Activity Level	MVC	Borg
1	a	5	6	1	1	2
2	a	4	4	1	1	1
3	a	3	6	2	1	2
4	a	4	6	1	1	2
5	a	3	10	2	1	3
6	a	3	6	1	1	2
7	b	4	4	4	2	2
8	b	2	6	4	1	3
9	b	3	4	4	1	2
10	b	4	7	2	1	3
11	b	3	6	4	1	3
12	b	3	5	2	1	2
13	b	3	5	4	1	3
14	b	3	3	4	1	1
	Avg.	3.4	5.6	2.6	1.1	2.2
	S.D.	0.78	1.70	1.34	0.27	0.70
	Min.	2.0	3.0	1.0	1.0	1.0
	Max.	5.3	10.0	4.0	2.0	3.0

Table 11-6: Strain index scores calculated with peak postures and %MVC

		Component scores						Risk output scores	
Subject	Facility	Intensity (%MVC)	Duration	Efforts/min	Posture	Speed	Duration	Index score	Risk level
1	a	9	0.5	3	3	1	0.75	30.4	3
2	a	6	0.5	0.5	1.5	1	0.75	1.7	1
3	a	6	1	1.5	2	1	1	18.0	3
4	a	6	1	1.5	3	1	0.75	20.3	3
5	a	3	1	3	3	1	0.75	20.3	3
6	a	3	1	1.5	3	1	0.75	10.1	3
7	b	6	1	3	3	1.5	1	81.0	3
8	b	3	1	3	3	1.5	1	40.5	3
9	b	6	1	3	3	1.5	1	81.0	3
10	b	6	1	1.5	3	1.5	1	40.5	3
11	b	6	1	3	2	1.5	1	54.0	3
12	b	3	1	1.5	2	1.5	1	13.5	3
13	b	6	1	3	2	1.5	1.5	81.0	3
14	b	6	1	3	3	1.5	1.5	121.5	3
	Avg.	5.4	0.9	2.3	2.6	1.3	1.0	43.8	2.9
	S.D.	1.74	0.18	0.89	0.56	0.26	0.25	35.19	0.53
	Min.	3.0	0.5	0.5	1.5	1.0	0.8	1.7	1.0
	Max.	9.0	1.0	3.0	3.0	1.5	1.5	121.5	3.0

Table 11-7: Strain index: effect of posture variable definition

		Posture multiplier score			Risk index		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	3	2	1	30.4	20.3	10.1
2	a	1.5	1.5	1	1.7	1.7	1.1
3	a	2	1.5	1	18.0	13.5	9.0
4	a	3	2	1.5	20.3	13.5	10.1
5	a	3	2	1	20.3	13.5	6.8
6	a	3	2	1	10.1	6.8	3.4
7	b	3	1.5	1	81.0	40.5	27.0
8	b	3	2	1	40.5	27.0	13.5
9	b	3	1.5	1	81.0	40.5	27.0
10	b	3	2	1	40.5	27.0	13.5
11	b	2	2	1.5	54.0	54.0	40.5
12	b	2	2	1.5	13.5	13.5	10.1
13	b	2	1.5	1	81.0	60.8	40.5
14	b	3	2	1	121.5	81.0	40.5
	Avg.	2.6	1.8	1.1	43.8	29.5	18.1
	S.D.	0.56	0.25	0.21	35.19	23.01	14.18
	Min.	1.5	1.5	1.0	1.7	1.7	1.1
	Max.	3.0	2.0	1.5	121.5	81.0	40.5

Rep. avg. – Repetition average posture

Table 11-8: Strain index: effect of exertion variable definition

		Exertion variable	
Subject	Facility	% MVC	Borg
1	a	9	9
2	a	6	6
3	a	6	9
4	a	6	9
5	a	3	13
6	a	3	9
7	b	6	6
8	b	3	9
9	b	6	6
10	b	6	9
11	b	6	9
12	b	3	6
13	b	6	6
14	b	6	3
	Avg.	5.4	7.8
	S.D.	1.74	2.42
	Min.	3.0	3.0
	Max.	9.0	13.0

Table 11-9: OCRA index calculated with peak postures and %MVC

		Component scores							Risk output scores	
Subject	Facility	Intensity (%MVC)	Wrist posture	Additional factors total	Hours recovery	Mins/day	Total reps/day	Rec. actions	OCRA Index	Risk level
1	a	0.01	0.6	0.9	1	178	1496	28.8	51.9	3
2	a	0.1	0.7	0.95	1	200	208	399	0.5	1
3	a	0.45	0.5	0.9	1	324	3970	1968.3	2.0	2
4	a	0.35	0.6	0.9	1	162	1779	918.5	1.9	2
5	a	0.45	0.6	0.9	1	200	2398	1458	1.6	2
6	a	0.45	0.5	0.9	1	214	2242	1300.1	1.7	2
7	b	0.45	0.5	0.9	1	416	8268	2527.2	3.3	2
8	b	0.75	0.6	0.8	0.1	416	9622	449.3	21.4	3
9	b	0.45	0.6	0.8	0.1	416	9388	269.6	34.8	3
10	b	0.2	0.5	0.8	1	416	5377	998.4	5.4	3
11	b	0.45	0.6	0.8	0.1	416	10259	269.6	38.1	3
12	b	0.45	0.6	0.8	1	416	5594	2695.7	2.1	2
13	b	0.45	0.6	0.8	0	500	13965	0	0	3
14	b	0.35	0.6	0.8	1	617	12497	3109.7	4.0	2
	Avg.	0.4	0.6	0.9	0.7	349.4	6218.8	1170.9	12.1	2.4
	S.D.	0.18	0.06	0.06	0.43	138.40	4440.06	1043.97	17.21	0.63
	Min.	0.01	0.5	0.8	0	162.0	208.0	0	0	1.0
	Max.	0.8	0.7	0.95	1.0	617.0	13965.0	3109.7	51.9	3.0

Table 11-10: OCRA: effect of posture variable definition

		Posture component scores			Risk index scores		
Subject	Facility	**Peak**	**Rep avg.**	**Overall average**	**Peak**	**Rep avg.**	**Overall average**
1	**a**	0.6	0.7	0.7	51.9	44.5	44.5
2	**a**	0.7	0.7	0.7	0.5	0.5	0.5
3	**a**	0.5	0.7	0.7	2.0	1.4	1.4
4	**a**	0.6	0.7	0.7	1.9	1.7	1.7
5	**a**	0.6	0.7	0.7	1.6	1.4	1.4
6	**a**	0.5	0.6	0.7	1.7	1.4	1.4
7	**b**	0.5	0.7	0.7	3.3	2.3	2.3
8	**b**	0.6	0.6	0.7	21.4	21.4	18.4
9	**b**	0.6	0.7	0.7	34.8	29.9	29.9
10	**b**	0.5	0.7	0.7	5.4	3.9	3.9
11	**b**	0.6	0.7	0.7	38.1	32.6	32.6
12	**b**	0.6	0.7	0.7	2.1	1.8	1.8
13	**b**	0.6	0.7	0.7	0	0	0
14	**b**	0.6	0.7	0.7	4.0	3.4	3.4
	Avg.	0.58	0.69	0.70	12.1	10.5	10.2
	S.D.	0.06	0.04	0.00	17.21	14.96	14.81
	Min.	0.50	0.60	0.70	0.0	0.0	0.0
	Max.	0.70	0.70	0.70	51.9	44.5	44.5

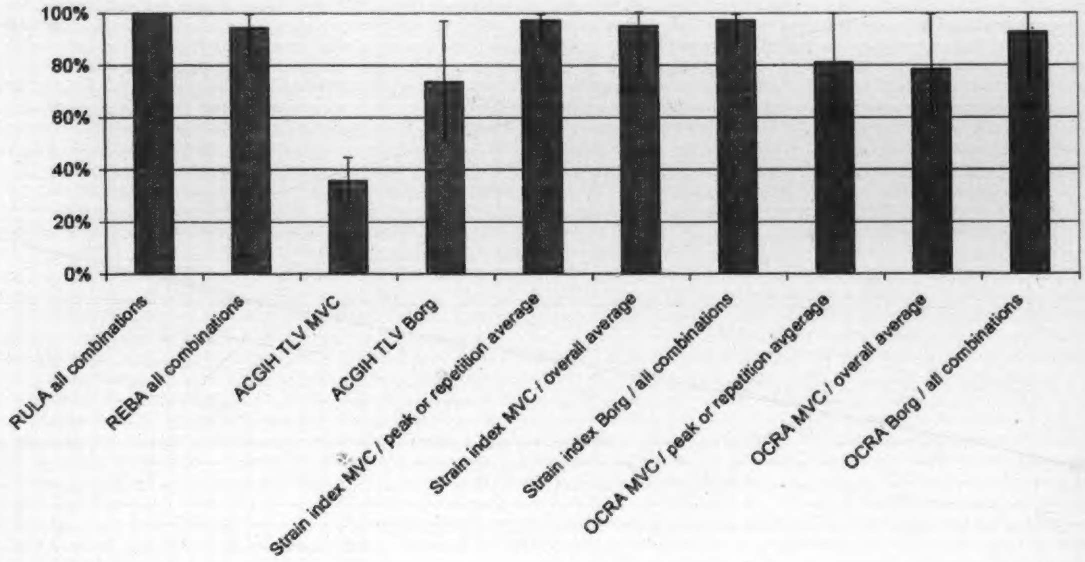
Rep. avg. – Repetition average posture

Table 11-11: OCRA: Effect of exertion variable definition

		Intensity component score	
Subject	**Facility**	**MVC**	**Borg**
1	**a**	0.01	0.01
2	**a**	0.1	0.2
3	**a**	0.45	0.01
4	**a**	0.35	0.01
5	**a**	0.45	0.01
6	**a**	0.45	0.01
7	**b**	0.45	0.2
8	**b**	0.75	0.01
9	**b**	0.45	0.2
10	**b**	0.2	0.01
11	**b**	0.45	0.01
12	**b**	0.45	0.01
13	**b**	0.45	0.1
14	**b**	0.35	0.45
	Avg.	0.38	0.09
	S.D.	0.18	0.13
	Min.	0.01	0.01
	Max.	0.75	0.45

Figure 11-1: Board edger operator performing primary (board turn) task.

Figure 11-2: Mean risk level as percentage of maximum by risk assessment method.



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Chapter 12 – Comparison of ergonomic risk assessments in a high risk sawmill occupation: lumber grader

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12.1 Introduction

Musculoskeletal injuries (MSI) in the Sawmill industry of Alberta, Canada, currently account for the largest percentage of total time loss (38%) and total cost (33%) of Workers Compensation Board claims (Jones and Kumar 2004a). MSI of the upper extremity accounted for more claims than any other body region. Given the impact of these injuries the development of effective prevention programs has become a priority of industrial health and safety initiatives. Evidence of casual association between the physical exposures of the job and MSI is now well established and mechanisms of injury based on established physiologic principles have been proposed (NIOSH 1997, Kumar 2001). Despite the presence of research linking MSI to physical exposures, specific cause-effect relationships remain elusive. Due to the absence of cause-effect relationships industrial prevention programs frequently rely on international physical exposure guidelines applied through ergonomic risk assessments to identify problem exposures and direct intervention. Ergonomic assessments consider the physical exposures in an integrated model of MSI precipitation which outputs a level of risk. The risk output and component scores pertaining to specific exposures are then used to direct intervention at problem exposures. Unfortunately little agreement currently exists between authors as to the physical exposures which should be considered and the relative role of those exposures in the precipitation of MSI (Jones and Kumar 2004b). One explanation for the lack of agreement between authors has been the limited ability to reliably examine the properties of the assessment proposed. In the past workplace exposure information was collected primarily by observation. The large measurement error due to exposure information being collected via observation is now understood (Lowe 2004). The lack of reliable exposure information has limited the ability of the authors to examine the agreement between methods and the association between the risk output of the methods and recorded incidence of injury. The current availability of tools capable of accurately and reliably measuring physical exposures makes the examination of the properties of the ergonomic assessment techniques possible. Very few studies are currently available which compare the results of multiple ergonomic assessments examining the upper extremity (Drinkaus et al. 2003, Bao et al. 2006). The use of quantified tools to measure physical exposures allows the sensitivity of the assessments to individual worker technique to be described and a risk score specific to the facility examined to be derived. Assessment of the same job within multiple facilities reporting differing incidence rates allows the ability of the assessments to differentiate between facilities with different incidence rates to be assessed. No studies could be located which sought to describe the ability of the assessments to detect differing levels of risk between groups of workers performing the same repetitive job. The use of quantified tools to record physical exposures allows multiple definitions of the exposures considered by the assessments to be applied. No literature could be located which sought to compare the assessment scores based on multiple variable definitions to determine the effect of variable definition. For the above reasons the objectives of this study were to: 1) describe and compare the results of five commonly used ergonomic risk assessments for the upper extremity; 2) examine the ability of the risk assessments to differentiate between facilities reporting differing incidence rates within the same job; 3) examine the effect of multiple definitions of posture and exertion on risk assessment output. The risk assessment methods compared in this study are the: Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), the quantified version of the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV), the Strain Index (SI), and the concise exposure index (OCRA) (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005). Each method's risk output has been broken into two scores: risk level and risk index. Risk assessment methods used in this study were selected based on semi objective criteria. All risk assessment methods considered for inclusion in this study generate an output which may be used to prioritize jobs and problem exposures for intervention. There is presently little literature examining the psychometric properties of ergonomic risk assessments individually. Similarly there is a paucity of literature examining the comparability of multiple risk assessment methods. Due to the lack of literature examining ergonomic risk assessment methods selection of methods to be compared in these studies based on an objective decision matrix was not possible. Methods used in these studies were selected based upon their common use in industrial MSI prevention initiatives. Risk index refers to the risk assessments' raw score output before that score is grouped and interpreted. Risk levels refer to the groupings of risk index scores which are interpreted into action levels etc. by the authors.

The lumber grader was chosen for further analysis in this study based on the high number of upper extremity MSIs recorded in the position during the 5 years of review. Incidence rates of recordable upper extremity MSI incidents in the lumber grader ranged from 0.09 to 0.25 per person year worked in the three facilities examined.

12.2 Methods

12.2.1 Occupation identification

Deriving incidence rates specific to the lumber grader position using compensation information is not possible given information describing the complete work force is not available (Jones and Kumar 2004a). For this reason the occupational health records of the three sawmill facilities participating was consulted to determine which production positions were commonly associated with injuries of a musculoskeletal nature to the upper extremity and the lumber grader position was selected.

12.2.2. Task description

The lumber grader is responsible for assigning a product grade to each piece of dimensional lumber leaving a sawmill. Board dimensions to be graded vary from 243.8 cm. to 609.6 cm. in length, 10.2 – 25.4 cm. in width, and 5.1 – 10.2 cm. in thickness. In order to assign a grade to piece of dimensional lumber the lumber grader must inspect the four sides of board. Inspecting all surfaces requires the board to be turned or flipped with the task dominant upper extremity. When a grade has been chosen the lumber grader places a mark with a reflective marker on the piece of dimensional lumber (enables automated sorting) with the remaining upper extremity. Boards were observed to vary in weight from 2.27 – 22.7 kg. dependent upon dimension, species of wood and moisture content. Figure 12-1 depicts the primary board turning task of the lumber grader.

12.2.3 Subject selection

Male and female workers presently performing the lumber grader position ages 18-65 were recruited at the three sawmill facilities studied. Subjects were excluded from the study if they reported; injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University health research ethics board. The study has been performed in accordance with ethical standards laid down in the 1964 Declaration of Helsinki. No female workers were present at the three facilities examined. 29 of 29 male subjects gave their informed consent and volunteered to take part in the study.

12.2.4 Data collection

12.2.4.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to turn boards as described in part 1 of this series (Jones and Kumar, submitted to the International Journal of Industrial Ergonomics 2006).

12.2.4.1.1 Posture: Postures required to perform the lumber grader position were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (turning boards). The repetition average posture was defined by randomly selecting 10 repetitions (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample. In the cases where body regions other than the forearm and wrist are considered (REBA, RULA, OCRA) only the postures of the forearm and wrist vary from peak excursions in the posture variable comparisons.

12.2.4.1.2 Duty cycle: The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

12.2.4.1.3 Frequency: Repetitions performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees (setting observed to best differentiate between repetitions of primary board turn task) at the proximal radio-ulnar joint (pronation/supination). Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used.

12.2.4.2 Exertion data acquisition

12.2.4.2.1 Percentage of maximum voluntary contraction: Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction and job simulated exertions as described in part one of this series (Jones and Kumar, submitted to the International Archives of Occupational and Environmental Health 2006). The average value resulting from the muscles assessed during the job simulated flexion trial and the job simulated pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the task components (flexion and pronation). The task components were then averaged to derive %MVC required to perform the primary (board turn) task.

12.2.4.2.2 Psychophysical measure of exertion: Following data collection during job performance workers were asked whether; “during the cycle were there job actions that required muscular effort of the upper limbs?” Workers were then asked to rate the exertion required to perform the actions from one to ten using the Borg CR-10 scale (Borg 1982). Borg ratings were then averaged and used in the ACGIH TLV, SI and OCRA assessments.

12.2.4.2.3 Dynamic force applied: Dynamic forces required were used as the exertion variable in the RULA and REBA methods. Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration recorded.

12.2.5 Data Analysis

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Kruskal-Wallis H test (alpha level 0.05) was used to determine if significant differences existed between facilities on risk assessment output scores (component, combined component, risk index, risk level). The Wilcoxin W test (alpha level of .05) was used to test whether significant differences existed between risk assessment scores derived using alternate posture and exertion variable definitions. Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

12.2.6 Risk Assessment methods

Risk indexes were calculated according to the primary literature describing their application (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005).

12.3 Results

12.3.1 Incidence of upper extremity musculoskeletal injury

The Alberta Workers Compensation Board data set indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the lumber grader position. Incidence rates calculated based on person year estimates from the three facilities averaged 0.23 (facility A), 0.25 (facility B) and 0.09 (facility C) recordable upper extremity incidents of a musculoskeletal nature per person year in the period examined.

12.3.2 Subject characteristics

The average work experience at the lumber grader position at time of assessment was 4.4 years (S.D. 4.9 yrs.). Average age of the lumber graders assessed was significantly different across the facilities assessed. Maximum mean deviation between the mean age of lumber graders was 9.8 years and mean ages ranged from 29.9 to 37.1 years. Average height of the lumber graders was also significantly different between facilities assessed. Maximum mean height difference was observed to be 9.5 cm. and mean heights ranged from 174.4 to 183.8 cm. Average weight of subjects did not differ between facilities assessed. Mean weight of the lumber graders assessed was 81.6 kg. (S.D. 14.7 kg.).

12.3.3 Risk assessment methods

Mean risk level for all risk assessments evaluated, with the exception of the ACGIH TLV when calculated with %MVC exertion variable, indicated a level of risk was associated with performance of the lumber grader position. Mean risk level assigned by method and variable combination is illustrated for the reader in figure 12-2.

12.3.3.1 RULA

12.3. 3.1.1 Between facility comparisons: The risk output of the RULA assessment was not sensitive to differences in recorded incidence rates between facilities. Component scores describing neck and trunk posture and the combined score of the trunk neck and legs (score D) were sensitive to inter facility differences ($p<.05$). The importance of the RULA assessments ability to detect differing neck and trunk postures between facilities assessed is difficult to assess in this study as neck and trunk postures were determined via observation. Quantified measures reflecting actual posture were only available for the forearm and wrist.

12.3.3.1.2 Effect of varying posture variable definition: Substituting repetition average forearm and wrist postures for peak postures resulted in no significant differences in combined upper extremity posture score. Substitution of overall average forearm and wrist postures for either peak or repetition average postures resulted in significantly different combined upper extremity posture scores (p<.01). Substituting overall average for peak forearm and wrist postures reduced combined upper extremity component scores by 34% in 10 of 29 subjects. Substituting overall average forearm and wrist postures for repetition average postures reduced combined upper extremity scores by 31% in 9 of 29 subjects. Forearm and wrist posture variable definition had no effect on RULA risk output scores. The effect of posture variable definition on the RULA assessment is difficult to assess in this study however given the RULA assessment considers many body regions and quantified exposure information enabling multiple posture variables to be calculated was only available for the forearm and wrist. Table 12-1 describes RULA component, combined component and risk output scores calculated with peak forearm and wrist postures. Table 12-2 describes the effect of varying forearm and wrist posture variable definition on combined upper extremity posture component and risk index scores.

12.3.3.2 REBA

12.3.3.2.1 Between facility comparisons: REBA risk output scores were not sensitive to differences in recorded incidence rates between facilities. REBA neck and trunk posture component scores did differentiate between facilities however (p<.05). The importance of the REBA assessments ability to detect differing neck and trunk postures between facilities assessed is difficult to assess in this study as neck and trunk postures were determined via observation.

12.3.3.2.2 Effect of varying posture variable definition: Substituting overall average forearm and wrist postures for either peak or repetition average postures resulted in significantly different combined upper extremity posture component scores (p<.01), REBA risk index scores (p<.05) and risk level scores (p<.05). Substituting repetition average forearm and wrist postures for either peak postures did not result in significant differences. Substituting overall average forearm and wrist postures for either peak or repetition average postures reduced combined upper extremity scores by an average of 31% in 9 of 29 subjects. Risk index and risk level scores were affected by an average of 19% in 6 of 29 subjects. The true effect of varying posture variable definition on RULA component, combined component, and risk output scores is not possible to assess in this study. The REBA assessment considers multiple body regions in addition to the forearm and wrist for which quantified exposure information enabling multiple posture variable definitions to be derived was not available. REBA component, combined component and risk output scores calculated with peak postures are presented for the reader in table 12-3. Effect of posture variable definition on combined upper extremity posture and risk output scores are presented in table 12-4.

12.3.3.3 ACGIH TLV

12.3.3.3.1 Between facility comparisons: ACGIH risk output did not differentiate between facilities assessed. ACGIH TLV hand activity level and Borg exertion component scores were significantly different between facilities assessed (p<.02) reflecting significant differences found between frequency and exertion variables recorded by Jones and Kumar 2006 (submitted to the International Archives of Occupational and Environmental Health).

12.3.3.3.2 Effect of varying exertion variable definition: Substituting the Borg exertion variable for the % MVC exertion variable resulted in significantly different exertion variable component scores (p<.001) and risk output scores (p<.001). Substituting the Borg exertion variable for the %MVC variable resulted in an average exertion component score increase of 352% in 29 of 29 subjects. Substitution of the Borg exertion variable for the %MVC variable increased risk level scores in 21 of 29 subjects (one level in 4 subjects and 2 levels in 17 subjects). These results indicate the risk output of the ACGIH TLV calculated using the Borg exertion variable is not comparable to that calculated with the %MVC exertion variable in 72% (21 of 29) subjects. ACGIH TLV component and risk output scores are presented for the reader in table 12-5.

12.3.3.4 Strain Index

12.3.3.4.1 Between facility comparisons: SI risk output did not differentiate between facilities. SI component scores reflecting time spent performing the task per day and Borg rating of exertion were sensitive to inter facility differences (p<.01). SI component combined component and risk output scores when calculated with peak postures and %MVC are described in table 12-6.

12.3.3.4.2 Effect of varying posture variable definition: Substituting repetition average for peak forearm and wrist postures, overall average for peak forearm and wrist postures and overall average for repetition average postures resulted in significantly different posture component and risk index scores (p<.01). Substituting repetition average for peak forearm and wrist postures resulted in an average risk index reduction of 43% in 25 of 29 subjects. Substituting overall average for peak forearm and wrist postures resulted in an average risk index reduction of 55% in 29 of 29 subjects. Finally, substituting overall average forearm and wrist postures for repetition average postures resulted in average risk index reductions of 42% in 18 of 29 subjects. Our results indicate posture variable definition significantly affects risk index output in the majority of subjects. Effect of varying posture variable definition on posture component score and risk index score are described for the reader in table 12-7.

12.3.3.4.3 Effect of varying exertion variable definition: Substitution of the Borg exertion variable for the %MVC exertion variable resulted in significantly different exertion component scores and risk index scores (p<.001). Substitution of the Borg exertion variable for the %MVC exertion variable resulted in an average exertion component score increase of 428% in 25 of 29 subjects. Our results indicate SI output is significantly affected by exertion variable definition. The effect of varying exertion variable definition on exertion component score and risk index are illustrated for the reader in table 12-8.

12.3.3.5 OCRA

12.3.3.5.1 Between facility comparisons: OCRA risk index scores differentiated between facilities assessed when calculated with all combinations of exertion and posture variables. Significant differences were not found between either facility A or B (recorded incidence rates of 0.23 and 0.25 respectively) and facility C (recorded incidence rate of 0.09). Significant differences were identified between facility A and facility B (p<.01). The importance of the finding of risk index scores differentiating between facilities is brought in to question as seemingly very little difference exists between facility A and B in recorded incidence rates. Limitations of the surveillance systems used by the facilities examined in this study prevent further investigation of this finding. OCRA component scores reflecting hours of recovery, minutes worked per day and Borg rating of exertion also differentiated between facilities (p<.05) reflecting actual differences observed by Jones and Kumar 2006 (submitted to the International Archives of Occupational and Environmental Health). The OCRA "recommended actions" combined component score also differentiated between facilities assessed (p<.05). OCRA component, combined component and risk output scores when calculated with peak postures and %MVC are described for the reader in table 12-9.

12.3.3.5.2 Effect of posture variable definition: Substitution of repetition average forearm and wrist postures for peak postures, overall average postures for peak postures and overall average for repetition average postures resulted in significantly different risk index scores (p<.0001). Substitution of repetition average postures for peak postures resulted in an average risk index reduction of 71% in 20 of 29 subjects. Substitution of overall average postures for peak postures resulted in an average risk index reduction of 83% in 28 of 29 subjects. Finally, substitution of overall average postures for repetition average postures resulted in an average risk index reduction of 42% in 17 of 29 subjects. Our findings indicate posture variable definition has a significant effect on OCRA risk output. Effect of varying posture variable definition on posture component score and risk index score are described for the reader in table 12-10.

12.3.3.5.3 Effect of varying exertion variable definition: Substitution of the Borg exertion variable for the %MVC exertion variable resulted in significantly different exertion component scores and risk index scores (p<.0001). Substitution of the Borg exertion variable for the %MVC variable resulted in an average risk index increase of 77% in 29 of 29 subjects. Our results indicate exertion variable definition significantly affects OCRA risk output. Effect of varying exertion variable definition on exertion component score and risk output is described for the reader in table 12-11.

12.4 Discussion

12.4.1 Risk output

Mean risk level assigned by all risk assessments evaluated, with the exception of the ACGIH TLV calculated with %MVC, assigned a level of risk associated with performance of the lumber grader position. All facilities assessed in this study indicated that a high rate of upper extremity MSIs currently took place annually in the lumber grader position. Seemingly significant differences in recorded incidence of upper extremity MSIs were present between facilities. Despite these recorded differences risk levels assigned were not sensitive to differences between facilities. Specific components of the risk assessments as well as the risk index output of the assessments were observed to be sensitive to inter facility differences. The components of the risk assessments which differentiated between facilities reflected actual differences recorded by Jones and Kumar (submitted to the International Journal of Industrial Ergonomics 2006). Evidence of causal associations between physical exposures and MSI, the observation of significant differences in exposures between facilities examined and the report of meaningfully different incidents rates suggests important differences influencing risk of MSI exist between facilities. Recorded incidence of upper extremity MSIs in facility A and B was approximately 250% higher than that recorded by facility C. The lack of sensitivity of risk level scores to inter facility differences suggests the information provided by risk level scores is insufficient to identify the problem exposures which have resulted in higher incidence of injury in facility A and B. The lack of sensitivity of risk level scores to inter facility differences suggests component and combined component scores must be used to identify problem exposures. Components of all risk assessments evaluated were sensitive to inter facility differences, only in the case of the OCRA assessment was the risk output of the assessment sensitive to inter facility differences however. The sensitivity of the OCRA's risk index score to inter facility differences suggests the relative role of the exposures considered by the OCRA assessment have been integrated in model which is associated with risk of injury. While the data described in this study suggest that the OCRA assessment was best able to assign the relative roles of the exposures considered limitations of the incidence data make this conclusion tentative.

12.4.2 Exposure variable definition

Definition of the posture and exertion variables have been shown to significantly impact component, combined component and risk output scores of the risk assessment methods assessed. Posture variable definition resulted in significantly different risk output scores in the SI and OCRA procedures affecting risk output scores as much as 83%. The primary literature describing the application of the ACGIH TLV, SI and OCRA procedures provide a scale by which either exertion information reflecting %MVC required or that collected using the Borg scale may be used in calculation of risk output (Moore et al. 1995, Colombini 1998, University of Michigan 2005). Exertion variable definition was found to significantly impact risk output scores in the ACGIH TLV, SI and OCRA procedures in the majority of subjects in all methods leading us to conclude the variables are not interchangeable. Clearly it is important for future studies to examine the impact of exposure variable definition on the predictive validity of the risk assessment methods. Limitations of the occupational health information used to determine incidence rates limit our analysis to the demonstration that the variable definitions result in significantly different risk output.

12.4.3 Limitations and future work

Further studies are needed to examine the properties of the risk assessment methods which have been described here. Further investigation of the association between risk output and incidence of injury based on standardized occupational health records are needed. While this study has recorded quantified demands in a representative sample of workers, neither the occupational health records of the facilities examined nor Workers Compensation Board dataset provides sufficient information to further examine the association between risk assessment scores and incidence of injury or impact of variable definition on predictive validity. With respect to facility occupational health records, each facilities method of recording incident is unique. The unique nature of the systems limits our ability to draw meaningful conclusions based on the grouped data and thus prevents any further exploration of the association between the risk output of the methods examined and incidence of injury. In the case of the Workers Compensation

Board dataset no information is collected on the total number of workers performing the lumber grader position and the resolution of the occupation performed data fields is not sufficient to identify specific production positions. Future studies examining the association between risk output and incidence of injury and the impact of exposure variable definition on the predictive validity of the assessment are needed.

12.5 Conclusion

In light of the foregoing data and discussion of the risk assessment methods the following general picture can be drawn: All the methodologies examined (with the exception of the ACGIH TLV) have identified a level of risk in the lumber grader position. While risk level scores agree their sensitivity to differing levels of risk between facilities suggests interpretation of risk output and component scores will be needed to identify at-risk exposures and direct intervention. The use of multiple exposure variable definitions in the calculation of the risk assessments has demonstrated the impact of exposure variable definition. In most cases risk output of the assessment is significantly affected by choice of posture and exertion variable. Further studies are needed which examine the relationship of risk output to incidence of injury (predictive validity) and the impact of exposure variable definition on predictive validity.

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Table 12-1: RULA scores calculated with peak postures

		Component scores							Combined component scores								Risk output scores	
		Posture Trunk/Neck/Legs			Posture Upper extremity				Trunk/Neck/Legs				Upper extremity				Risk index	Risk level
Subject	Facility	Neck	Trunk	Legs	Upper arm	Lower arm	Wrist	Wrist twist	Posture	Muscle	Force	Score D	Posture	Muscle	Force	Score C	Grande score	Risk Level
1	a	1	3	1	2	2	4	1	3	1	2	6	4	1	2	7	7	4
2	a	1	3	1	2	2	4	1	3	1	2	6	4	1	2	7	7	4
3	a	2	3	1	2	2	4	1	4	1	2	7	4	1	2	7	7	4
4	a	1	2	1	3	3	4	2	2	1	2	5	5	1	2	8	7	4
5	a	1	3	1	2	2	4	1	3	1	2	6	4	1	2	7	7	3
6	a	2	2	1	2	2	4	1	2	1	2	5	4	1	2	7	7	4
7	a	2	1	1	2	3	4	1	2	1	2	5	4	1	2	7	7	3
8	b	2	1	1	1	2	4	1	2	1	2	5	3	1	2	6	6	3
9	b	3	2	1	1	2	4	1	3	1	2	6	3	1	2	6	7	3
10	b	4	1	1	1	2	4	1	5	1	2	8	3	1	2	6	7	3
11	b	4	1	1	2	3	4	1	5	1	2	8	4	1	2	7	7	4
12	b	3	1	1	1	3	4	1	3	1	2	6	4	1	2	7	7	4
13	b	3	1	1	1	3	4	1	3	1	2	6	4	1	2	7	7	4
14	b	4	1	1	3	2	4	1	5	1	2	8	5	1	2	8	7	4
15	b	4	4	1	5	3	4	2	7	1	2	10	8	1	2	11	7	4
16	b	4	1	1	2	2	4	1	5	1	2	8	4	1	2	7	7	4
17	b	3	1	1	2	2	4	1	3	1	2	6	3	1	2	6	7	3
18	b	4	1	1	2	3	4	1	5	1	2	8	4	1	2	7	7	4
19	c	3	1	1	1	2	4	1	3	1	2	6	3	1	2	6	7	3
20	c	3	1	1	1	3	4	1	3	1	2	6	4	1	2	7	7	4
21	c	3	1	1	1	3	4	1	3	1	2	6	4	1	2	7	7	4
22	c	3	1	1	1	2	4	2	3	1	2	6	3	1	2	6	7	3
23	c	3	1	1	1	2	4	1	3	1	2	6	3	1	2	6	7	3
24	c	4	1	1	1	2	4	1	5	1	2	8	3	2	1	6	7	3
25	c	4	1	1	1	2	4	1	5	1	2	8	3	1	2	6	7	3
26	c	4	1	1	2	2	4	1	5	1	2	8	4	1	2	7	7	4
27	c	4	4	1	5	2	4	1	7	1	2	10	7	1	2	10	7	4
28	c	4	1	1	2	2	4	1	5	1	2	8	4	1	2	7	7	4
29	c	4	4	1	4	2	4	1	7	1	2	10	5	1	2	8	7	4
	Avg.	3.0	1.7	1.0	1.9	2.3	4.0	1.1	3.9	1.0	2.0	6.9	4.0	1.0	2.0	7.0	7.0	3.6
	S.D.	1.07	1.07	0.00	1.13	0.47	0.00	0.31	1.51	0.00	0.00	1.51	1.15	0.19	0.19	1.15	0.19	0.49
	Min.	1	1	1	1	2	4	1	2	1	2	5	3	1	1	6	6	3
	Max.	4	4	1	5	3	4	2	7	1	2	10	8	2	2	11	7	4

Table 12-2: RULA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	4	4	3	7	7	7
2	a	4	4	3	7	7	7
3	a	4	4	3	7	7	7
4	a	5	5	5	7	7	7
5	a	4	4	4	7	7	7
6	a	4	4	4	7	7	7
7	a	4	4	4	7	7	7
8	b	3	3	3	6	6	6
9	b	3	3	3	7	7	7
10	b	3	3	3	7	7	7
11	b	4	4	4	7	7	7
12	b	4	4	3	7	7	7
13	b	4	4	4	7	7	7
14	b	5	5	4	7	7	7
15	b	8	7	7	7	7	7
16	b	4	4	4	7	7	7
17	b	3	3	3	7	7	7
18	b	4	4	4	7	7	7
19	c	3	3	3	7	7	7
20	c	4	4	3	7	7	7
21	c	4	4	4	7	7	7
22	c	3	3	3	7	7	7
23	c	3	3	2	7	7	7
24	c	3	3	3	7	7	7
25	c	3	3	3	7	7	7
26	c	4	4	4	7	7	7
27	c	7	7	6	7	7	7
28	c	4	4	3	7	7	7
29	c	5	5	5	7	7	7
	Avg.	4.0	4.0	3.7	7.0	7.0	7.0
	S.D.	1.15	1.04	1.04	0.19	0.19	0.19
	Min.	3	3	2	6	6	6
	Max.	8	7	7	7	7	7

Rep. avg. – Repetition average posture

Table 12-3: REBA index calculated with peak postures

		Component scores						Combined component scores								Risk output scores	
		Trunk/Neck/Legs			Upper extremity			Trunk/Neck/Legs			Upper extremity			Multiple body part		Risk index	Risk level
Subject	Facility	Trunk	Neck	Legs	Upper arm	Lower arm	Wrist	Posture total	Force	Score A	Posture Total	Grip	Score B	Score C	Activity score	Grand score	Risk Level
1	a	3	1	1	2	1	3	2	1	3	3	1	4	3	1	4	2
2	a	3	1	1	2	1	3	3	1	4	3	1	4	4	1	5	2
3	a	3	2	1	2	1	3	4	1	5	3	1	4	5	1	6	2
4	a	2	1	1	3	2	3	2	1	3	5	1	6	5	1	6	2
5	a	3	1	1	2	1	3	2	1	3	3	1	4	3	1	4	2
6	a	2	2	1	2	1	3	3	1	4	3	1	4	4	1	5	2
7	a	1	2	1	2	1	3	1	1	2	3	1	4	3	1	4	2
8	b	1	1	1	1	1	3	1	1	2	2	1	3	2	1	3	1
9	b	2	2	1	1	1	3	3	1	4	2	1	3	4	1	5	2
10	b	1	3	1	1	1	3	3	1	4	2	1	3	4	1	5	2
11	b	1	3	1	2	1	3	3	1	4	3	1	4	4	1	5	2
12	b	1	2	1	1	1	3	1	1	2	2	1	3	2	1	3	1
13	b	1	2	1	1	2	3	1	1	2	3	1	4	3	1	4	2
14	b	1	3	1	3	1	3	3	1	4	5	1	6	6	1	7	2
15	b	3	3	1	5	2	3	5	1	6	8	1	9	10	1	11	4
16	b	1	3	1	2	1	3	3	1	4	3	1	4	4	1	5	2
17	b	1	2	1	2	1	3	1	1	2	3	1	4	3	1	4	2
18	b	1	3	1	2	1	3	3	1	4	3	1	4	4	1	5	2
19	c	1	2	1	1	1	3	1	1	2	2	1	3	2	1	3	1
20	c	1	2	1	1	2	3	1	1	2	3	1	4	3	1	4	2
21	c	1	2	1	1	2	3	1	1	2	3	1	4	3	1	4	2
22	c	1	2	1	1	1	3	1	1	2	2	1	3	2	1	3	1
23	c	1	3	1	1	1	3	3	1	4	2	1	3	4	1	5	2
24	c	1	3	1	1	1	3	3	1	4	2	1	3	4	1	5	2
25	c	1	3	1	1	1	3	3	1	4	2	1	3	4	1	5	2
26	c	1	3	1	2	1	3	3	1	4	3	1	4	4	1	5	2
27	c	3	3	1	5	1	3	5	1	6	8	1	9	10	1	11	4
28	c	1	3	1	2	1	3	3	1	4	3	1	3	4	1	5	2
29	c	4	3	1	4	1	3	6	1	7	5	1	6	9	1	10	3
	Avg.	1.6	2.3	1.0	1.9	1.2	3.0	2.6	1.0	3.6	3.2	1.0	4.2	4.2	1.0	5.2	2.0
	S.D.	0.94	0.75	0.00	1.13	0.38	0.00	1.35	0.00	1.35	1.57	0.00	1.59	2.11	0.00	2.11	0.68
	Min.	1	1	1	1	1	3	1	1	2	2	1	3	2	1	3	1
	Max.	4	3	1	5	2	3	6	1	7	8	1	9	10	1	11	4

Table 12-4: REBA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	3	3	2	4	4	4
2	a	3	3	2	5	5	5
3	a	3	3	2	6	6	5
4	a	5	5	5	6	6	6
5	a	3	3	3	4	4	4
6	a	3	3	3	5	5	5
7	a	3	3	2	4	4	3
8	b	2	2	2	3	3	3
9	b	2	2	2	5	5	5
10	b	2	2	2	5	5	5
11	b	3	3	2	5	5	5
12	b	2	2	2	3	3	3
13	b	3	3	3	4	4	4
14	b	5	5	4	7	7	6
15	b	8	8	8	11	11	11
16	b	3	3	3	5	5	5
17	b	3	3	2	4	4	3
18	b	3	3	3	5	5	5
19	c	2	2	2	3	3	3
20	c	3	3	2	4	4	3
21	c	3	3	3	4	4	4
22	c	2	2	2	3	3	3
23	c	2	2	2	5	5	5
24	c	2	2	2	5	5	5
25	c	2	2	2	5	5	5
26	c	3	3	3	5	5	5
27	c	8	8	7	11	11	10
28	c	3	3	3	5	5	5
29	c	5	5	5	10	10	10
	Avg.	3.2	3.2	2.9	5.2	5.2	5.0
	S.D.	1.57	1.57	1.53	2.11	2.11	2.07
	Min.	2	2	2	3	3	3
	Max.	8	8	8	11	11	11

Rep. avg. – Repetition average posture

Table 12-5: ACGIH TLV scores calculated with %MVC and Borg exertion variables

		Component scores			Risk level	Risk level
Subject	Facility	% MVC exertion score	Borg exertion score	Hand Activity Level	MVC	Borg
1	a	1	6	5	1	3
2	a	1	7	5	1	3
3	a	1	5	4	1	3
4	a	1	8	5	1	3
5	a	1	7	5	1	3
6	a	1	7	5	1	3
7	a	1	4	5	1	3
8	b	1	5	4	1	3
9	b	1	3	4	1	1
10	b	1	5	4	1	3
11	b	1	4	3	1	2
12	b	1	3	4	1	1
13	b	1	3	4	1	1
14	b	1	3	4	1	1
15	b	1	4	5	1	3
16	b	2	3	4	1	1
17	b	1	7	4	1	3
18	b	1	4	4	1	2
19	c	1	3	5	1	2
20	c	1	3	5	1	2
21	c	1	3	4	1	1
22	c	2	5	4	1	3
23	c	1	6	4	1	3
24	c	1	5	5	1	3
25	c	1	5	5	1	3
26	c	1	3	4	1	1
27	c	1	4	5	1	3
28	c	1	7	4	1	3
29	c	1	3	4	1	1
	Avg.	1.1	4.7	4.4	1.0	2.3
	S.D.	0.26	1.61	0.56	0.00	0.89
	Min.	1	3	3	1	1
	Max.	2	8	5	1	3

Table 12-6: Strain index scores calculated with peak postures and %MVC

		Component scores						Risk output scores	
Subject	Facility	Intensity (%MVC)	Duration	Efforts/min	Posture	Speed	Duration	Index score	Risk level
1	a	1	2	3	1.5	1.5	1	13.5	3
2	a	1	2	3	1.5	1.5	1	13.5	3
3	a	1	1.5	3	2	1.5	1	13.5	3
4	a	1	1.5	3	3	1.5	1	20.3	3
5	a	1	1.5	3	2	1.5	1	13.5	3
6	a	1	1.5	3	3	1.5	1	20.3	3
7	a	1	1.5	3	3	1.5	1	20.3	3
8	b	1	1.5	3	2	1.5	0.25	3.4	2
9	b	1	1	2	2	1.5	0.25	1.5	1
10	b	1	1.5	3	3	1.5	1	20.3	3
11	b	3	1.5	3	3	1.5	1	60.8	3
12	b	1	1.5	3	3	1.5	1	20.3	3
13	b	1	1.5	3	3	1.5	0.75	15.2	3
14	b	3	1.5	3	2	1.5	0.75	30.4	3
15	b	1	1.5	3	3	2	1	27.0	3
16	b	3	1.5	3	3	1.5	1	60.8	3
17	b	3	1.5	3	3	1.5	0.75	45.6	3
18	b	3	1.5	3	3	2	0.75	60.8	3
19	c	1	1.5	3	3	1.5	1	20.3	3
20	c	3	1.5	3	3	1.5	1.5	91.1	3
21	c	1	1.5	3	3	1.5	1	20.3	3
22	c	3	1.5	3	3	1.5	1	60.8	3
23	c	1	1.5	3	1.5	1.5	1	10.1	3
24	c	1	1.5	3	3	2	1	27.0	3
25	c	1	1.5	3	1.5	1.5	1	10.1	3
26	c	3	1	3	3	1.5	1.5	60.8	3
27	c	3	1.5	3	3	1.5	1.5	91.1	3
28	c	3	1.5	3	2	1.5	1	40.5	3
29	c	1	1.5	3	3	1.5	1.5	30.4	3
	Avg.	1.7	1.5	3.0	2.6	1.6	1.0	31.8	2.9
	S.D.	0.97	0.19	0.19	0.60	0.15	0.29	24.47	0.41
	Min.	1	1	2	1.5	1.5	0.25	1.5	1
	Max.	3	2	3	3	2	1.5	91.1	3

Table 12-7: Strain index: effect of posture variable definition

		Posture multiplier score			Risk index		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	1.5	1	1	13.5	9.0	9.0
2	a	1.5	1.5	1	13.5	13.5	9.0
3	a	2	1.5	1	13.5	10.1	6.8
4	a	3	3	2	20.3	20.3	13.5
5	a	2	1	1	13.5	6.8	6.8
6	a	3	1.5	1	20.3	10.1	6.8
7	a	3	1.5	1	20.3	10.1	6.8
8	b	2	1	1	3.4	1.7	1.7
9	b	2	1	1	1.5	0.8	0.8
10	b	3	1.5	1.5	20.3	10.1	10.1
11	b	3	3	1	60.8	60.8	20.3
12	b	3	2	1	20.3	13.5	6.8
13	b	3	1.5	1	15.2	7.6	5.1
14	b	2	1.5	1	30.4	22.8	15.2
15	b	3	1.5	1	27.0	13.5	9.0
16	b	3	1.5	1.5	60.8	30.4	30.4
17	b	3	2	1	45.6	30.4	15.2
18	b	3	1.5	1.5	60.8	30.4	30.4
19	c	3	2	1	20.3	13.5	6.8
20	c	3	2	1	91.1	60.8	30.4
21	c	3	1	1	20.3	6.8	6.8
22	c	3	2	1	60.8	40.5	20.3
23	c	1.5	1	1	10.1	6.8	6.8
24	c	3	3	1.5	27.0	27.0	13.5
25	c	1.5	1	1	10.1	6.8	6.8
26	c	3	1.5	1	60.8	30.4	20.3
27	c	3	2	1	91.1	60.8	30.4
28	c	2	1	1	40.5	20.3	20.3
29	c	3	1.5	1	30.4	15.2	10.1
	Avg.	2.6	1.6	1.1	31.8	20.4	12.9
	S.D.	0.60	0.59	0.25	24.47	17.06	8.83
	Min.	1.5	1	1	1.5	0.75	0.75
	Max.	3	3	2	91.1	60.8	30.4

Rep. avg. – Repetition average posture

Table 12-8: Strain index: effect of exertion variable definition

		Exertion variable	
Subject	Facility	% MVC	Borg
1	a	1	9
2	a	1	9
3	a	1	6
4	a	1	13
5	a	1	9
6	a	1	9
7	a	1	6
8	b	1	6
9	b	1	3
10	b	1	6
11	b	3	6
12	b	1	3
13	b	1	3
14	b	3	3
15	b	1	6
16	b	3	3
17	b	3	9
18	b	3	6
19	c	1	3
20	c	3	3
21	c	1	3
22	c	3	6
23	c	1	9
24	c	1	6
25	c	1	6
26	c	3	3
27	c	3	6
28	c	3	9
29	c	1	3
	Avg.	1.7	5.9
	S.D.	0.97	2.69
	Min.	1	3
	Max.	3	13

Table 12-9: OCRA index calculated with peak postures and %MVC

		Component scores							Risk output scores	
Subject	Facility	Intensity (%MVC)	Posture	Additional factors total	Hours recovery	Mins/day	Total reps/day	Rec. actions	OCRA Index	Risk level
1	a	0.85	0.5	0.9	0.1	405	16241	464.74	34.95	3
2	a	0.85	0.5	0.9	0.1	405	14712	464.74	31.66	3
3	a	1	0.3	0.9	0.1	405	10300	328.05	31.4	3
4	a	0.85	0.3	0.9	0.1	405	11808	278.84	42.35	3
5	a	0.85	0.3	0.9	0.1	405	12760	278.84	45.76	3
6	a	0.85	0.3	0.9	0.1	405	13193	278.84	47.31	3
7	a	1	0.5	0.9	0.1	405	11535	546.75	21.09	3
8	b	0.85	0.3	0.9	0.9	54	2129	371.79	5.72	3
9	b	1	0.6	0.9	1	54	953	874.8	1.09	2
10	b	0.85	0.3	0.9	0.45	270	10125	836.53	12.1	3
11	b	0.85	0.5	0.9	0.45	270	8202	1394.21	5.88	3
12	b	1	0.6	0.9	0.45	270	8365	1968.3	4.25	3
13	b	0.85	0.3	0.9	0.6	211	9204	871.64	10.56	3
14	b	0.85	0.3	0.9	0.6	211	6867	871.64	7.88	3
15	b	0.85	0.6	0.9	0.45	270	8213	1673.06	4.91	3
16	b	0.65	0.3	0.9	0.45	270	10353	639.7	16.18	3
17	b	0.85	0.3	0.9	0.6	211	7024	871.64	8.06	3
18	b	0.85	0.6	0.9	0.6	211	6835	1743.28	3.92	2
19	c	0.85	0.5	0.9	0.1	436	19867	500.31	39.71	3
20	c	0.85	0.3	0.9	0	487	18651	0	0	3
21	c	0.85	0.3	0.9	0.1	409	13567	281.6	48.18	3
22	c	0.75	0.3	0.9	0.1	436	19044	264.87	71.9	3
23	c	0.85	0.3	0.9	0.45	325	12439	1006.93	12.35	3
24	c	0.85	0.3	0.9	0.6	247	8745	1020.36	8.57	3
25	c	1	0.3	0.9	0.1	436	17457	353.16	49.43	3
26	c	0.85	0.6	0.9	0	585	14562	0	0	3
27	c	0.85	0.3	0.9	0	487	15879	0	0	3
28	c	0.85	0.6	0.9	0.1	436	16826	600.37	28.03	3
29	c	0.85	0.6	0.9	0	487	14707	0	0	3
	Avg.	0.866	0.407	0.900	0.303	341.655	11743.552	647.758	20.456	2.931
	S.D.	0.075	0.133	0.000	0.285	128.105	4754.154	527.513	19.767	0.258
	Min.	0.65	0.3	0.9	0	54	953	0	0	2
	Max.	1	0.6	0.9	1	585	19867	1968.3	71.9	3

Table 12-10: OCRA: effect of posture variable definition

		Posture component scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	0.5	0.7	0.7	34.9	25.0	25.0
2	a	0.5	0.6	0.7	31.7	26.4	22.6
3	a	0.3	0.7	0.7	31.4	13.5	13.5
4	a	0.3	0.3	0.7	42.3	42.3	18.1
5	a	0.3	0.7	0.7	45.8	19.6	19.6
6	a	0.3	0.5	0.7	47.3	28.4	20.3
7	a	0.5	0.7	0.7	21.1	15.1	15.1
8	b	0.3	0.5	0.7	6.4	3.8	2.7
9	b	0.6	0.6	0.7	1.1	1.1	0.9
10	b	0.3	0.6	0.6	12.1	6.1	6.1
11	b	0.5	0.7	0.7	5.9	4.2	4.2
12	b	0.6	0.7	0.7	4.2	3.6	3.6
13	b	0.3	0.5	0.7	10.6	6.3	4.5
14	b	0.3	0.6	0.7	7.9	3.9	3.4
15	b	0.6	0.6	0.7	4.9	4.9	4.2
16	b	0.3	0.3	0.6	16.2	16.2	8.1
17	b	0.3	0.7	0.7	8.1	3.5	3.5
18	b	0.6	0.6	0.7	3.9	3.9	3.4
19	c	0.5	0.6	0.6	39.7	33.1	33.1
20	c	0.3	0.6	0.6	0.0	0.0	0.0
21	c	0.3	0.6	0.7	48.2	24.1	20.7
22	c	0.3	0.3	0.7	71.9	71.9	30.8
23	c	0.3	0.5	0.7	12.4	7.4	5.3
24	c	0.3	0.3	0.3	8.6	8.6	8.6
25	c	0.3	0.5	0.7	49.4	29.7	21.2
26	c	0.6	0.7	0.7	0.0	0.0	0.0
27	c	0.3	0.6	0.7	0.0	0.0	0.0
28	c	0.6	0.6	0.7	28.0	28.0	24.0
29	c	0.6	0.6	0.7	0.0	0.0	0.0
	Avg.	0.407	0.569	0.672	20.5	14.8	11.1
	S.D.	0.133	0.128	0.080	19.75	16.27	10.17
	Min.	0.3	0.3	0.3	0	0	0
	Max.	0.6	0.7	0.7	71.89942	71.9	33.09

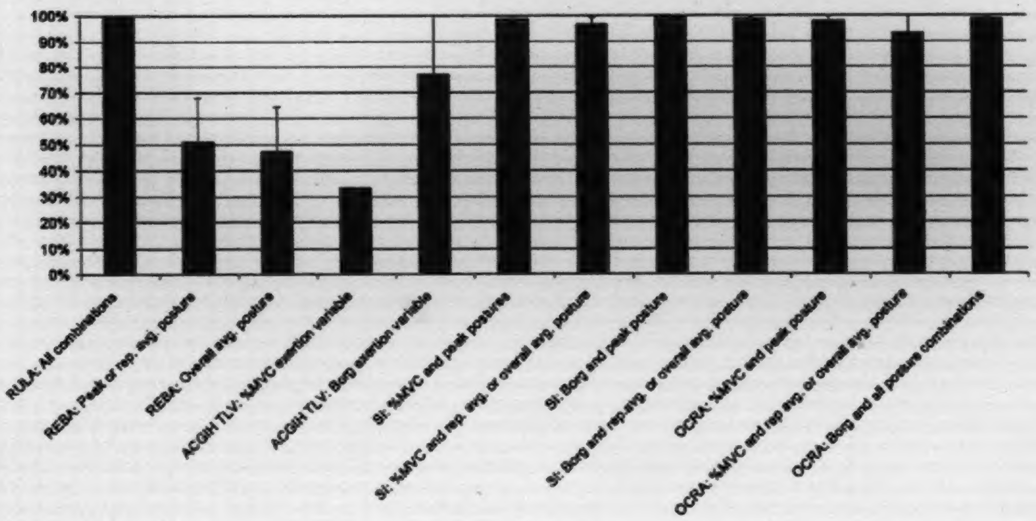
Rep. avg. – Repetition average posture

Table 12-11: OCRA: Effect of exertion variable definition

		Intensity component score	
Subject	Facility	MVC	Borg
1	a	0.85	0.01
2	a	0.85	0.01
3	a	1	0.01
4	a	0.85	0.01
5	a	0.85	0.01
6	a	0.85	0.01
7	a	1	0.2
8	b	0.85	0.01
9	b	1	0.45
10	b	0.85	0.01
11	b	0.85	0.2
12	b	1	0.45
13	b	0.85	0.45
14	b	0.85	0.45
15	b	0.85	0.2
16	b	0.65	0.45
17	b	0.85	0.01
18	b	0.85	0.2
19	c	0.85	0.45
20	c	0.85	0.45
21	c	0.85	0.45
22	c	0.75	0.01
23	c	0.85	0.01
24	c	0.85	0.01
25	c	1	0.01
26	c	0.85	0.45
27	c	0.85	0.2
28	c	0.85	0.01
29	c	0.85	0.45
	Avg.	0.87	0.19
	S.D.	0.075	0.201
	Min.	0.65	0.01
	Max.	1	0.45

Figure 12-1: Lumber grader performing primary (board turn) task

Figure 12-2: Mean risk level as percentage of maximum by risk assessment method



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Chapter 13 – Comparison of ergonomic risk assessments in a repetitive high risk sawmill occupation: saw-filer

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13.1 Introduction

In 2003 a review of Workers Compensation Board claims revealed a significant impact of musculoskeletal injuries (MSI) on the sawmill industry of Alberta, Canada (Jones and Kumar 2004). In the period reviewed MSIs accounted for 32% of total claims cost and 38% of total time loss more than any other injury category. MSIs to the upper extremity accounted for a higher percentage of claims than any other body part. Given the impact of MSIs industrial health and safety initiatives are now focused on MSI prevention. The established relationship between MSIs and the physical demands of the job has focused prevention efforts on the identification of problem exposures for intervention (NIOSH 1997). Ergonomic risk assessments which consider multiple physical exposures in an integrated model of risk prediction are currently being used to direct intervention. Currently, little agreement exists as to the physical exposures which should be considered in an assessment of risk and the relative role of those variables in the precipitation of MSI (Jones and Kumar 2004b).

Few studies are available which compare the results of multiple assessments in the same worker population (Drinkaus et al 2003, Bao et al. 2006). Studies which present and compare the risk assessment scores of multiple methods are needed to assess agreement between methods and gain an understanding of inter subject variability. Understanding inter subject variability is necessary to determine if more than one worker performing a repetitive job must be assessed to obtain a representative risk assessment for that site or facility. One explanation for the paucity of literature examining the comparability of peer reviewed assessments is the limited ability of worksite evaluators to collect accurate and reliable exposure information by observation. Recent studies have documented the large measurement errors due to exposure information being collected by observation (Lowe 2005). The use of tools capable of reliably collecting exposure information in the worksite (such as electrogoniometers and surface electromyography) allows researchers to begin to assess the comparability of commonly used ergonomic risk assessment methods.

Authors of three of the five methods examined here have proposed scales by which either percentage of maximum voluntary contraction (%MVC) or Borg ratings of exertion may be used to define the exertion component of the assessment. Work site evaluators measuring exposure by observation typically define postures by either the peak postures observed, average posture required to perform the primary task or overall average posture, use of quantified demands information allows the comparability of these posture variable definitions to be examined. No studies of the effect of varying either exertion or posture variable definition could be located.

For the above reasons the aims of this study are to: 1) compare the results of 5 ergonomic risk assessment methods calculated with quantified physical exposure information, 2) examine the ability of the component, combined component and risk output scores to differentiate between facilities reporting different rates of injuries, 3) examine the association between risk output and recorded incidence rates and 4) examine the effect of multiple definitions of the posture and exertion variable on the risk assessment methodologies examined.

The risk assessment methods compared in this study are the: Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), the quantitative version of the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV), the Strain Index (SI), and the concise exposure index (OCRA) (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005). Risk assessment methods used in this study were selected based on semi objective criteria. All risk assessment methods considered for inclusion in this study generate an output which may be used to prioritize jobs and problem exposures for intervention. There is presently little literature examining the psychometric properties of ergonomic risk assessments individually. Similarly there is a paucity of literature examining the comparability of multiple risk assessment methods. Due to the lack of literature examining ergonomic risk assessment methods selection of methods to be compared in these studies based on an objective decision matrix was not possible. Methods used in these studies were selected based upon their common use in industrial MSI prevention initiatives. Each method's risk output has been broken into two scores: risk level and risk index. Risk index refers to the risk assessments' raw score output before that score is grouped and interpreted. Risk levels refer to the groupings of risk index scores which are interpreted into action levels etc. by the original authors.

The saw filer was chosen for further analysis in this study based on the high number of upper extremity MSIs recorded in the position during the 5 years of review. Incidence rates of recordable upper extremity MSI incidents in the saw filer ranged from 0.12 to 0.86 per person year worked in the four facilities examined.

13.2 Methods

13.2.1 Occupation identification

Deriving incidence rates for the saw-filer position using compensation information was not possible given information describing the complete work force was not available (Jones and Kumar, 2004a). For this reason the occupational health records of four sawmill facilities were consulted to determine which production positions were commonly associated with injuries of musculoskeletal nature to the upper extremity, and the saw-filer position was selected.

13.2.2 Task description

The primary function of the saw filer position is to maintain the condition of the round saws, band saws, and chipper blades (knives). The efficiency of the sawmilling process is dependent upon the condition of this equipment. The saw filer is responsible for repairing saw blades and knives during equipment breakdown and scheduled maintenance. Once the saw blades are removed, the blades and knives are sharpened via automated processes. Round saws require the saw filer remove imperfections in the saw by hammering the saw blade with a 1.13 kg. hammer. This same process is then repeated in order to tension the saw blade. Imperfection correction and tensioning requires the saw be placed on an anvil and hammered. Time required to correct imperfections and tension saws is variable and is dependent upon dimension and condition of the saw blade. The physical exposures described here were those measured during the primary task only; hammering of round saws (imperfection correction and tensioning). The primary hammering task of the saw filer is illustrated in figure 13-1.

13.2.3 Subject selection

Workers presently performing the saw-filer position were recruited at four sawmill facilities. Subjects were excluded from the study if they reported; injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University Health Research Ethics Board. No female sawfilers were present in the four sawmill facilities examined. 15 subjects volunteered to take part in the study out of the population of 15 (100% participation rate).

13.2.4 Data collection

13.2.4.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to hammer saws as described in part 1 of this series (Jones and Kumar, Submitted to International Journal of Industrial Ergonomics 2006).

13.2.4.1.1 Posture: Postures required to perform the saw filer job were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (hammering saws). The repetition average (rep. avg.) posture was defined by randomly selecting 10 repetitions (hammer strokes), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average (O.A.) posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample. In the cases where body regions other than the forearm and wrist are considered (REBA, RULA, OCRA) only the postures of the forearm and wrist vary from peak excursions in the posture variable comparisons.

13.2.4.1.2 Duty cycle: The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

13.2.4.1.3 Frequency:. Repetitions performed during the sample were determined by inspecting the radial/ulnar deviation waveform recorded by the bi-axial electrogoniometer. Radial/ulnar deviation was used to define repetition due to its cyclical nature in performance of the job (hammering saws) and clear repeated trace as recorded by the analysis system used.

13.2.4.2 Exertion data acquisition

13.2.4.2.1 Percentage of maximum voluntary contraction: Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction and job simulated exertions as described in part one of this series (Jones and Kumar, submitted to the International Journal of Industrial Ergonomics 2006). The average value resulting from the muscles assessed during the job simulated radial deviation trial and the job simulated ulnar deviation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the task components (radial and ulnar deviation). The task components were then averaged to derive %MVC required to perform the primary (hammer saws) task.

13.2.4.2.2 Psychophysical measure of exertion: Following data collection during job performance workers were asked whether; "during the cycle were there job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the exertion required to perform the actions from one to ten using the Borg CR-10 scale

(Borg 1982). Borg ratings of the exertion necessary to hammer saws were then used in the ACGIH TLV, SI and OCRA assessments.

13.2.4.2.3 Dynamic force applied: Dynamic forces required were used as the exertion variable in the RULA and REBA methods. Dynamic force required to hammer saws was calculated assuming the center of mass of the hammer was in the middle of the hammer head.

13.2.5 Data Analysis

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Kruskal-Wallis H test (alpha level 0.05) was used to determine if significant differences existed between facilities on risk assessment output scores (component, combined component, risk index, risk level). The Wilcoxin W test (alpha level of .05) was used to test whether significant differences existed between risk assessment scores derived using alternate posture and exertion variable definitions. Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

13.2.6 Risk Assessment methods

Risk indexes were calculated according to the primary literature describing their application (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005).

13.3 Results

13.3.1 Incidence of upper extremity musculoskeletal injury

Alberta Workers Compensation Board data indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the saw-filer position. Incidence rates calculated based on person year estimates were available from three of the four facilities examined. Average incidence of reportable musculoskeletal events per person year worked were 0.12 (facility A) 0.32 (facility B) and 0.86 (facility D) during the period assessed (1997-2002).

13.3.2 Subject characteristics

The average age of subjects was 44 (S.D. 9.5), average height of subjects was 178 cm (S.D. 7.5 cm), and average weight of subjects was 86.1 kg. (S.D. 14.84 kg.). Average work experience at the saw-filer position at time of assessment was 11.5 years (S.D. 6.83 yrs.). All subjects assessed were male.

13.3.3 Risk assessment methods

Mean risk level for all risk assessments evaluated, with the exception of the ACGIH TLV when calculated with %MVC exertion variable, indicated a level of risk was associated with performance of the saw filer job. Mean risk level assigned by method and variable combination is illustrated for the reader in figure 13-2.

13.3.3.1 RULA

13.3.3.1.1 Between facility comparisons: RULA component, combined component and risk output scores calculated with dynamic forces and peak forearm and wrist postures are presented for the reader in table 13-1. Significant differences (p<.05) between facilities assessed were observed for several RULA component and combined component scores. Component scores sensitive to inter facility differences included the posture variables associated with the trunk, neck, and upper arms. Combined component scores sensitive to inter facility differences included the combined trunk/neck/legs posture variable, total trunk score (RULA score D), combined upper extremity posture score, and total upper extremity score (RULA score C). Significant differences between facilities were observed in several frequency variables (hours/day, repetitions/day, total exposure) and one posture variable (radial/ulnar deviation). Significant differences in RULA scores measuring frequency were not found between facilities (RULA muscle use score). Significant differences between RULA scores measuring wrist and forearm postures were also not identified. These results indicate the number of scoring categories in the RULA components measuring wrist posture forearm posture and task frequency were not sufficient to identify actual differences measured with quantified tools. The ability of the RULA assessment to identify significant differences in neck, trunk and upper arm postures between facilities cannot be validated based on quantified demands data as only the forearm and wrist were measured by quantified means. No variation between facilities was observed in either risk index or risk level scores of the RULA assessment.

13.3.3.1.2 Effect of varying posture variable definition: Significantly different ($p<.025$) combined upper extremity posture scores were obtained when repetition average or overall average forearm and wrist posture values were substituted for peak postures. No significant difference was obtained when overall average forearm and wrist posture values were substituted for repetition average values. Substituting repetition average values for peak values resulted in an average combined upper extremity posture score reduction of 19% in 5 of 15 subjects. Substituting overall average for peak forearm and wrist postures resulted in an average reduction in combined upper extremity posture scores of 19% in 8 of 15 subjects. Posture variable definition had no effect on RULA risk output. Table 13-2 describes the effect of varying forearm and wrist posture variable definition on combined upper extremity posture component scores and risk index scores.

13.3.3.2 REBA

13.3.3.2.1 Between facility comparisons: REBA component, combined component, and risk output scores calculated with dynamic force applied and peak forearm and wrist postures are presented for the reader in table 13-3. Significant differences ($p<.05$) between facilities assessed were observed for REBA component, combined component, and risk output scores. Component scores sensitive to inter facility differences included the posture variables associated with the trunk, neck, upper arm and lower arm. Combined component scores sensitive to inter facility differences included: the combined posture scores of the trunk/neck/legs, the combined upper extremity posture score, total trunk/neck/legs score (REBA score A), total upper extremity score (REBA score B) and the total combined score (score C). Both REBA risk index and REBA risk level scores were sensitive to inter facility differences (p<.05). REBA risk levels did not correctly identify the facilities reporting the highest incidence rates of upper extremity MSI however, facility D which recorded the highest incidence rate (0.86) was had the lowest average risk level score (1.7). Similar to RULA component scores REBA component scores measuring task frequency, wrist posture and forearm posture were unable to detect actual differences detected by quantified tools. These findings indicate the number or resolution of scoring categories in REBA components measuring task frequency and wrist/forearm posture is insufficient to detect actual differences.

13.3.3.2.2 Effect of varying posture variable definition: Significantly different (p<.025) combined upper extremity posture scores were obtained when overall average forearm and wrist posture values were substituted for peak postures. No significant difference was obtained when repetition average values were substituted for peak values or overall average values were substituted for repetition average values. Substituting overall average values for peak values resulted in an average combined upper extremity posture score reduction of 17% in 6 of 15 subjects. Effect of varying posture variable definition on combined upper extremity posture and risk output scores are presented in table 13-4.

13.3.3.3 ACGIH TLV

13.3.3.3.1 Between facility comparisons: ACGIH TLV component, combined component, and risk output scores calculated with both Borg and %MVC exertion variables are presented for the reader in table 13-5. No significant differences between facilities assessed were observed for any ACGIH TLV component, combined component or risk output scores. No significant differences between facilities were identified in either the frequency measures or exertion measures considered by the ACGIH TLV (Jones and Kumar 2006). The lack of significant differences between facilities assessed in the frequency variables considered by the ACGIH TLV prevents the evaluation of whether the resolution of the component scores is sufficient to detect actual differences.

13.3.3.3.2 Effect of varying exertion variable definition: Significantly different exertion component scores (p<.01) and risk level scores (p<.025) were obtained when the Borg exertion variable definition was substituted for the %MVC exertion variable definition.

Substitution of the Borg for the %MVC exertion variable definition elevated exertion variable scores by an average of 308% in 13 of 15 subjects and increased risk level assigned in 7 of 15 subjects. Risk level assigned was increased by 1 level in 4 of 15 subjects and 2 levels in 3 of 15 subjects. Our findings indicate the Borg and %MVC exertion variable definitions result in significantly different risk level assigned in a large percentage of subjects and are therefore not comparable as they have been defined here.

13.3.3.4 Strain Index

13.3.3.4.1 Between facility comparisons: SI component combined component and risk output scores when calculated with peak postures and %MVC are described for the reader in table 13-6. SI posture and hours per day component scores differentiated between facilities assessed (p<.05) reflecting actual differences identified by Jones and Kumar 2006. These results indicate that the SI component scores measuring duration per day and posture were of sufficient resolution to detect actual differences. No significant differences between facilities were found for risk output scores generated. Despite the lack of statistically significant differences between facilities in risk index scores a seemingly meaningful trend was present. Average SI risk index scores specific to facility were observed to increase as recorded incidence of injury increased in the facilities for which incidence information was available. Recorded incidence rates by facility in the 5 years examined (1997-2002) were 0.12, 0.32, and 0.86 in facilities A,B, and D respectively. Average SI risk index scores in facilities A,B, and D were 7.5, 9.2 and 19.5 respectively. These findings suggest that SI risk index scores may be sensitive to meaningful differences in incidence of MSI between facilities within the same job.

13.3.3.4.2 Effect of varying posture variable definition: Substitution of repetition average, or overall average, forearm and wrist postures for peak postures resulted in significantly different SI posture component (p<.001), risk index (p<.001), and risk level scores (p<.01). Substitution of repetition average forearm and wrist posture values for peak posture values resulted in an average risk index reduction of 40% in 14 of 15 subjects. Substitution of overall average for peak forearm and wrist posture values resulted in an average risk index reduction of 45% in 15 of 15 subjects. Substitution of repetition average forearm and wrist posture values for peak posture values reduced risk levels scores in 7 subjects by one risk level. Substitution of overall average for peak forearm and wrist posture values reduced risk level scores by one level in 10 subjects. Effect of varying posture variable definition on posture component score and risk index score are described for the reader in table 13-7.

13.3. 3.4.3 Effect of varying exertion variable definition: Substitution of the Borg exertion variable for the %MVC exertion variable resulted in significantly different exertion component scores ($p<.05$) and risk index scores ($p<.05$). Substitution of the Borg exertion variable for the %MVC exertion variable affected scores in 12 of 15 subjects in both directions. In 8 of 14 subjects, substitution of the Borg exertion variable increased risk index scores by an average of 413%. In 4 of 15 subjects the Borg exertion variable decreased risk index scores by an average of 67%. Our results indicate that substitution of the Borg exertion variable for the %MVC exertion variables resulted in significantly different risk index scores and that the exertion variable definitions are therefore not comparable as they have been defined here. The effect of varying exertion variable definition on exertion component score and risk index are illustrated for the reader in table 13-8.

13.3.3.5 OCRA

13.3.3.5.1 Between facility comparisons: OCRA component, combined component and risk output scores calculated with peak postures and %MVC are described for the reader in table 13-9. Significant differences ($p<.05$) between facilities were observed in OCRA components measuring hours of recovery, minutes performing the task per day and total repetitions. Significant differences between facilities in duration of task and total repetitions were also measured by quantified means by Jones and Kumar 2006 indicating sufficient resolution is present to detect actual differences. No significant differences were observed in either risk index or risk level scores. Despite the lack of statistically significant differences between facilities on risk output scores a seemingly meaningful trend in risk index scores was present. Average OCRA risk index scores specific to facility were observed to increase as recorded incidence of injury increased in all facilities in which incidence information was available. Recorded incidence rates by facility in the 5 years examined were 0.12, 0.32, and 0.86 in facilities A,B, and D respectively. Average OCRA risk index scores in facilities A,B, and D were 2, 26 and 79 respectively. Importantly, the risk index scores of 2 of 3 subjects in facility D were adjusted to obtain the average score used in the trend reported. Maximum OCRA risk index score is 0 which results from greater than 8 hours without recovery. Because the effect of a zero score is to reduce the facility average risk index 0 scores were replaced by the maximum score observed across facilities in calculating the facility average. Our findings suggest that OCRA risk index scores may be sensitive to meaningful differences in incidence of MSI between facilities within the same job.

13.3.3.5.2 Effect of varying posture variable definition: Substitution of repetition average or overall average forearm and wrist posture values for peak postures resulted in significantly different posture component and risk index scores (p<.01). Substitution of either repetition average or overall average postures for peak postures resulted in an average risk index reduction of 34% in 12 of 15 subjects. Our results indicate posture variable definition has a significant effect on risk index scores but does not influence risk level scores. Effect of posture variable definition on posture component score and risk index score are described for the reader in table 13-10.

13.3.3.5.3 Effect of varying exertion variable definition: Defining the exertion variable according to the Borg criteria and not the %MVC criteria resulted in significantly different (<.01) exertion component, risk index and risk level scores. Substitution of Borg exertion variable for the %MVC variable increased risk index scores by an average of 62% in 14 of 15 subjects and reduced the risk index score by 18% in 1 subject. Substitution of the Borg exertion variable for the %MVC exertion variable increased risk level scores by 1 level in 8 of 15 subjects. Our results indicate calculation of the OCRA index based on the Borg exertion variable definition results in significantly different risk output scores in the majority of subjects indicating the exertion variables examined are not comparable as they were defined here. Effect of exertion variable definition on exertion component score and risk output is described for the reader in table 13-11.

13.4 Discussion

13.4.1 Assessment of risk

Mean risk level assigned by all methods examined, with the exception of the ACGIH TLV calculated with %MVC, indicate a level of risk is present in the saw filer position. Meaningfully different incidence rates were recorded by the facilities assessed and significantly different levels of physical exposure have been identified. The evidence base supporting the role of physical exposures in precipitation of MSI suggests that differences in physical exposures between facilities may be responsible for differences in recorded incidence rates. If the differences in physical exposure observed play a role in the increased incidence of injury these differences should be detected by, and reflected in, risk assessment scores. Very little variability was found between facilities examined in risk level scores. The lack of variability in risk level scores between facilities suggests identification of problem exposures responsible for the different rates of MSI will rely on interpretation of risk index and component scores. Within facilities component scores were observed to vary by subject. Inter-subject variability within facilities suggests that more than one worker must be assessed to obtain a representative score. This representative score may then function to guide the work site evaluators to problem exposures.

Significant differences between facilities were found in frequency of motions and total exposures by Jones and Kumar (2006). A trend of increasing frequency of motion and total exposure was observed as recorded incidence of injury increased. Those methods whose components were sensitive to differences in frequency and postures observed (SI and OCRA) were best able to differentiate between the facilities reporting different incidence rates. This finding suggests the differences in the frequency variables observed may be related to increased risk of MSI and that the role of frequency and total exposure in precipitation of MSI may be captured.

It is established that both the individual exposures and the combined effect of multiple exposures are related to the precipitation of MSI. Each methodology examined here attempts to account for the combined role of the physical exposures by considering the exposures in an integrated model of MSI precipitation which derives a risk output score. Only the risk output of the REBA assessment was capable of differentiating between facilities on risk level score. Increasing REBA risk level scores were not associated with increasing recorded rates of upper extremity MSI however. While statistically significant differences between facilities in risk output scores were not present for the SI and OCRA methods a trend of increasing average risk index scores with increasing recorded incidence was present. There is suggestive evidence therefore that the SI and OCRA procedures were best able to account for the integrated effect of multiple exposures in the precipitation of MSI.

13.4.2 Effect of varying posture and exertion variable definition

The use of quantified demands information in the calculation of the risk assessment methods examined allowed the effect of multiple posture and exertion variable definitions to be examined. The original authors of the ACGIH TLV, SI and OCRA procedures have provided scales by which either %MVC or Borg ratings of exertion may be used to define the exertion component. Our results have indicated that in most cases substitution of the Borg exertion component for the %MVC component has resulted in significantly different exertion component and/or risk output scores. Our results indicate therefore that the exertion variables, as they have been defined here, are not comparable.

Work site evaluators are commonly afforded three possible definitions of the posture variable if they are collecting demands information via observation. The effect of those three definitions on component scores and risk output has been explored here and shown to have a significant effect. Importantly, quantified demands data were only available for the wrist and forearm in this study and thus the true effect of posture variable definition on those assessments considering a larger number of body regions cannot be assessed (i.e. RULA and REBA). Further studies are needed which examine the effect of variable definition on the predictive validity of the assessments to begin to define optimal posture and exertion variable definitions

13.4.3 Limitations and future work

The two primary limitations of this study are; 1) the sample size and 2) limitations of the occupational health records used. 100% of workers present in the facilities examined at the time of assessment volunteered to take part in the study. Despite the participation rate insufficient subject numbers are present to examine the association between facility scores and incidence of injury statistically. Inferential statistics used in this study have a limited ability to examine the association between recorded incidence of MSI and risk assessment scores. While a difference between all facilities may be identified differences between individual facilities may not, primarily due to the small sample sizes collected. It is necessary to identify significant differences between two individual facilities to assess whether average risk scores are associated with increasing recorded incidence. For this reason trends in risk assessment scores are described and conclusions are limited to suggestive.

A prerequisite to determining whether observed differences in risk assessment scores between facilities are meaningful is the presences of rates of incidence of MSI in each facility. Accurate information regarding the rates of MSI is only available from the occupational health records of the facilities examined (Jones and Kumar 2004). The surveillance system of each facility is unique, however. The unique nature of the systems limits our ability to draw conclusions based on the grouped data and thus prevents the further exploration of the association between the risk output of the methods examined and incidence of injury. Additional studies of the relationship between risk assessment scores and incidence of MSI are needed based upon a standardized surveillance system. Such a system is not currently available in the sawmill industry of Alberta, Canada.

13.5 Conclusion

In light of the foregoing data and discussion of the risk assessment methods the following general picture emerges: all risk assessment methodologies evaluated (with the exception of the ACGIH TLV) agree a level of risk is associated with performance of the saw filer job. Considerable variation in recorded incidence of MSI exists between facilities suggesting previously observed differences in physical exposures may play a role in increasing risk of injury. Risk level output of all methods examined was unable to identify facilities reporting higher risk of injury. The inability of risk level output to identify differing levels of risk present suggests interpretation of risk index and component scores is necessary to identify problem exposures. Components measuring posture and frequency of the SI and OCRA procedures were sensitive to actual differences measured. Increasing average risk index output by facility of both the strain index and OCRA procedures was observed to increase as recorded incidence of MSI increased; this suggests the combined role of the physical exposures in precipitation of MSI has been captured. Limitations in the sample size and comparability of the occupational health records available limit conclusions made to suggestive. Definition of the exertion and posture variable was observed to have a significant effect on component scores and risk output. Further studies are needed to examine the effect of posture and exertion variable output on the predictive validity of the risk assessment methods examined.

13.6 Acknowledgement

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Table 13-1: RULA scores calculated with peak postures

		Component scores							Combined component scores								Risk output scores	
		Posture Trunk/Neck/Legs			Posture Upper extremity				Trunk/Neck/Legs				Upper extremity				Risk index	Risk level
Subject	Facility	Neck	Trunk	Legs	Upper arm	Lower arm	Wrist	Wrist twist	Posture	Muscle	Force	Score D	Posture	Muscle	Force	Score C	Grande score	Risk Level
1	a	4	6	1	4	2	4	1	8	1	2	11	5	1	2	8	7	4
2	a	5	5	1	3	3	4	1	8	1	2	11	5	1	2	8	7	4
3	a	5	5	1	3	3	4	1	8	1	2	11	5	1	2	8	7	4
4	b	5	5	1	5	3	4	2	8	1	2	11	8	1	2	11	7	4
5	b	5	5	1	4	3	4	1	8	1	2	11	6	1	2	9	7	4
6	b	5	5	1	5	3	4	2	8	1	2	11	8	1	2	11	7	4
7	b	5	5	1	6	3	4	1	8	1	2	11	9	1	2	12	7	4
8	b	6	5	1	4	3	4	1	9	1	2	12	6	1	2	9	7	4
9	c	5	5	1	5	3	4	1	8	1	2	11	7	1	2	10	7	4
10	c	5	5	1	4	3	4	1	8	1	2	11	6	1	2	9	7	4
11	c	5	4	1	5	3	4	1	8	1	2	11	7	1	2	10	7	4
12	c	5	5	1	4	3	4	1	8	1	2	11	6	1	2	9	7	4
13	d	4	2	1	1	3	4	1	5	1	2	8	4	1	2	7	7	4
14	d	3	1	1	1	1	4	1	3	1	2	6	3	1	2	6	7	4
15	d	4	2	1	1	2	4	1	5	1	2	8	3	1	2	6	7	4
	Avg.	4.7	4.3	1.0	3.7	2.7	4.0	1.1	7.3	1.0	2.0	10.3	5.9	1.0	2.0	8.9	7.0	4.0
	S.D.	0.70	1.45	0.00	1.59	0.59	0.00	0.35	1.6	0.00	0.00	1.63	1.77	0.00	0.00	1.77	0.00	0.00
	Min.	3.0	1.0	1.0	1.0	1.0	4.0	1.0	3.00	1.0	2.0	6.0	3.0	1.0	2.0	6.0	7.0	4.0
	Max.	6.0	6.0	1.0	6.0	3.0	4.0	2.0	9.0	1.0	2.0	12.0	9.0	1.0	2.0	12.0	7.0	4.0

Table 13-2: RULA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	5	4	4	7	7	7
2	a	5	5	5	7	7	7
3	a	5	5	5	7	7	7
4	b	8	7	7	7	7	7
5	b	6	6	5	7	7	7
6	b	8	7	7	7	7	7
7	b	9	9	9	7	7	7
8	b	6	5	5	7	7	7
9	c	7	7	7	7	7	7
10	c	6	6	5	7	7	7
11	c	7	7	7	7	7	7
12	c	6	6	6	7	7	7
13	d	4	4	3	7	7	7
14	d	3	2	2	7	7	7
15	d	3	3	3	7	7	7
	Avg.	5.9	5.5	5.3	7.0	7.0	7.0
	S.D.	1.77	1.8	1.88	0.00	0.00	0.00
	Min.	3.0	2.00	2.0	7.0	7.0	7.0
	Max.	9.0	9.0	9.0	7.0	7.0	7.0

Rep. avg. – Repetition average posture

Table 13-3: REBA index calculated with peak postures

		Component scores						Combined component scores								Risk output scores	
		Trunk/Neck/Legs			Upper extremity			Trunk/Neck/Legs			Upper extremity			Multiple body part		Risk index	Risk level
Subject	Facility	Trunk	Neck	Legs	Upper arm	Lower arm	Wrist	Posture total	Force	Score A	Posture Total	Grip	Score B	Score C	Activity score	Grand score	Risk Level
1	a	5	3	1	4	2	3	7	1	8	7	0	7	10	1	11	4
2	a	4	3	1	3	2	3	6	1	7	5	0	5	9	1	10	3
3	a	4	3	1	3	2	3	6	1	7	5	0	5	9	1	10	3
4	b	4	3	1	5	2	3	6	1	7	8	0	8	10	1	11	4
5	b	4	3	1	4	2	3	6	1	7	7	0	7	9	1	10	3
6	b	4	3	1	5	2	3	6	1	7	8	0	8	10	1	11	4
7	b	4	3	1	6	2	3	6	1	7	9	0	9	10	1	11	4
8	b	4	3	1	4	2	3	6	1	7	7	0	7	9	1	10	3
9	c	4	3	1	5	2	3	6	1	7	8	0	8	10	1	11	4
10	c	4	3	1	4	2	3	6	1	7	7	0	7	9	1	10	3
11	c	3	3	1	5	2	3	5	1	6	8	0	8	9	1	10	3
12	c	4	3	1	4	2	3	6	1	7	7	0	7	9	1	10	3
13	d	2	2	1	1	2	3	3	1	4	3	0	3	4	1	5	2
14	d	1	2	1	1	1	3	1	1	2	2	0	2	2	1	3	1
15	d	2	3	1	1	1	3	4	1	5	2	0	2	4	1	5	2
	Avg.	3.5	2.9	1.0	3.7	1.9	3.0	5.3	1.0	6.3	6.2	0.0	6.2	8.2	1.0	9.2	3.1
	S.D.	1.06	0.35	0.00	1.59	0.35	0.00	1.54	0.00	1.54	2.27	0.00	2.27	2.60	0.00	2.60	0.88
	Min.	1.0	2.0	1.0	1.0	1.0	3.0	1.0	1.0	2.0	2.0	0.0	2.0	2.0	1.0	3.0	1.0
	Max.	5.0	3.0	1.0	6.0	2.0	3.0	7.0	1.0	8.0	9.0	0.0	9.0	10.0	1.0	11.0	4.0

Table 13-4: REBA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	7	6	6	11	11	11
2	a	5	5	5	10	10	10
3	a	5	5	5	10	10	10
4	b	8	8	8	11	11	11
5	b	7	7	7	10	10	10
6	b	8	8	7	11	11	10
7	b	9	9	9	11	11	11
8	b	7	6	6	10	10	10
9	c	8	8	8	11	11	11
10	c	7	7	6	10	10	10
11	c	8	8	8	10	10	10
12	c	7	6	6	10	10	10
13	d	3	3	2	5	5	5
14	d	2	2	2	3	3	3
15	d	2	2	2	5	5	5
	Avg.	6.2	6.0	5.8	9.2	9.2	9.1
	S.D.	2.27	2.24	2.27	2.60	2.60	2.56
	Min.	2.0	2.0	2.0	3.0	3.0	3.0
	Max.	9.0	9.0	9.0	11.0	11.0	11.0

Rep. avg. – Repetition average posture

Table 13-5: ACGIH TLV scores calculated with %MVC and Borg exertion variables

		Component scores			Risk level	Risk level
Subject	Facility	% MVC exertion score	Borg exertion score	Hand Activity Level	MVC	Borg
1	a	1	3	1	1	1
2	a	1	3	4	1	1
3	a	1	0.5	4	1	1
4	b	1	7	3	1	3
5	b	1	3	3	1	1
6	b	1	8	3	1	3
7	b	1	3	3	1	1
8	b	1	4	5	1	3
9	c	1	4	4	1	2
10	c	1	4	3	1	2
11	c	1	2	3	1	1
12	c	2	2	3	1	1
13	d	1	5	3	1	2
14	d	1	5	3	1	2
15	d	1	2	5	1	1
	Avg.	1.0	3.7	3.3	1.0	1.7
	S.D.	0.22	1.96	0.98	0.00	0.82
	Min.	0.6	0.5	1.0	1.0	1.0
	Max.	1.6	8.0	5.0	1.0	3.0

Table 13-6: Strain index scores calculated with peak postures and %MVC

Component scores								Risk output scores	
Subject	Facility	Intensity (%MVC)	Duration	Efforts/min	Posture	Speed	Duration	Index score	Risk level
1	a	3	0.5	1	3	1	1	4.5	2
2	a	3	1	3	2	1	0.5	9.0	3
3	a	3	1	3	2	1	0.5	9.0	3
4	b	3	1	3	2	1	0.75	13.5	3
5	b	1	1	3	2	1	0.75	4.5	2
6	b	1	1	3	2	1	0.75	4.5	2
7	b	3	1	3	2	1	0.75	13.5	3
8	b	1	1	3	3	1.5	0.75	10.1	3
9	c	3	1.5	3	3	1	1	40.5	3
10	c	1	1	3	3	1	1	9.0	3
11	c	3	1	3	3	1	0.75	20.3	3
12	c	3	1	2	3	1	0.75	13.5	3
13	d	1	1	3	1.5	1	1	4.5	2
14	d	3	1	3	2	1	1.5	27.0	3
15	d	3	1	3	2	1	1.5	27.0	3
	Avg.	2.3	1.0	2.8	2.4	1.0	0.9	14.0	2.7
	S.D.	0.98	0.19	0.56	0.55	0.13	0.30	10.46	0.46
	Min.	1.0	0.5	1.0	1.5	1.0	0.5	4.5	2.0
	Max.	3.0	1.5	3.0	3.0	1.5	1.5	40.5	3.0

Table 13-7: Strain index: effect of posture variable definition

		Posture multiplier score			Risk index		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	3	2	1	4.5	3.0	1.5
2	a	2	1.5	1.5	9.0	6.8	6.8
3	a	2	1.5	1.5	9.0	6.8	6.8
4	b	2	1	1	13.5	6.8	6.8
5	b	2	1.5	1	4.5	3.4	2.3
6	b	2	1.5	1.5	4.5	3.4	3.4
7	b	2	1	1	13.5	6.8	6.8
8	b	3	1.5	1.5	10.1	5.1	5.1
9	c	3	1.5	1.5	40.5	20.3	20.3
10	c	3	1.5	1.5	9.0	4.5	4.5
11	c	3	1.5	1.5	20.3	10.1	10.1
12	c	3	1.5	1.5	13.5	6.8	6.8
13	d	1.5	1.5	1	4.5	4.5	3.0
14	d	2	1	1	27.0	13.5	13.5
15	d	2	1.5	1	27.0	20.3	13.5
	Avg.	2.4	1.4	1.3	14.0	8.1	7.4
	S.D.	0.55	0.26	0.26	10.46	5.63	5.07
	Min.	1.5	1.0	1.0	4.5	3.0	1.5
	Max.	3.0	2.0	1.5	40.5	20.3	20.3

Rep. avg. – Repetition average posture

Table 13-8: Strain index: effect of exertion variable definition

		Exertion variable	
Subject	Facility	% MVC	Borg
1	a	3	3
2	a	3	3
3	a	3	1
4	b	3	9
5	b	1	3
6	b	1	13
7	b	3	3
8	b	1	6
9	c	3	6
10	c	1	6
11	c	3	1
12	c	3	1
13	d	1	6
14	d	3	6
15	d	3	1
	Avg.	2.3	4.5
	S.D.	0.98	3.40
	Min.	1.0	1.0
	Max.	3.0	13.0

Table 13-9: OCRA index calculated with peak postures and %MVC

		Component scores							Risk output scores	
Subject	Facility	Intensity (%MVC)	Posture	Additional factors total	Hours recovery	Mins/day	Total reps/day	Rec. actions	OCRA Index	Risk level
1	a	0.85	0.6	0.9	1	297	2147	4089.7	0.5	1
2	a	0.85	0.6	0.9	0.9	81	3117	1003.8	3.1	2
3	a	0.85	0.7	0.9	0.8	108	3844	1388.0	2.8	2
4	b	0.85	0.7	0.9	0.7	168	4685	1889.2	2.5	2
5	b	0.85	0.7	0.9	0.8	2.31	3486	29.7	117.4	3
6	b	0.85	0.7	0.9	0.8	139	3038	1786.4	1.7	2
7	b	0.85	0.7	0.9	0.8	139	5097	1786.4	2.9	2
8	b	1	0.6	0.9	0.8	105	5097	1360.8	3.8	2
9	c	0.75	0.7	0.9	0.45	270	10694	1722.3	6.2	3
10	c	0.85	0.6	0.9	0.45	324	6935	2007.7	3.5	2
11	c	0.85	0.6	0.9	0.6	216	4726	1784.6	2.7	2
12	c	0.75	0.7	0.9	1	216	3859	3061.8	1.3	2
13	d	1	1	0.9	0.6	240	7991	3888.0	2.1	2
14	d	0.85	1	0.9	0	540	21600	0.0	0.0	3
15	d	0.75	0.7	0.9	0	540	33478	0.0	0.0	3
	Avg.	0.9	0.7	0.9	0.6	225.7	7986.3	1719.9	10.0	2.2
	S.D.	0.07	0.13	0.00	0.31	154.06	8529.61	1246.90	29.75	0.56
	Min.	0.8	0.6	0.9	0.0	2.3	2147.0	0.0	0.0	1.0
	Max.	1.0	1.0	0.9	1.0	540.0	33478.0	4089.7	117.4	3.0

Table 13-10: OCRA: effect of posture variable definition

		Posture component scores			Risk index scores		
Subject	**Facility**	**Peak**	**Rep avg.**	**Overall average**	**Peak**	**Rep avg.**	**Overall average**
1	a	0.6	1	1	0.5	0.3	0.3
2	a	0.6	1	1	3.1	1.9	1.9
3	a	0.7	1	1	2.8	1.9	1.9
4	b	0.7	1	1	2.5	1.7	1.7
5	b	0.7	1	1	117.4	82.2	82.2
6	b	0.7	1	1	1.7	1.2	1.2
7	b	0.7	1	1	2.9	2.0	2.0
8	b	0.6	1	1	3.8	2.3	2.3
9	c	0.7	1	1	6.2	4.4	4.4
10	c	0.6	1	1	3.5	2.1	2.1
11	c	0.6	1	1	2.7	1.6	1.6
12	c	0.7	1	1	1.3	0.9	0.9
13	d	1	1	1	2.1	2.1	2.1
14	d	1	1	1	0.0	0.0	0.0
15	d	0.7	1	1	0.0	0.0	0.0
	Avg.	0.7	1.0	1.0	10.0	7.0	7.0
	S.D.	0.13	0.00	0.00	29.75	20.84	20.84
	Min.	0.6	1.0	1.0	0.0	0.0	0.0
	Max.	1.0	1.0	1.0	117.4	82.2	82.2

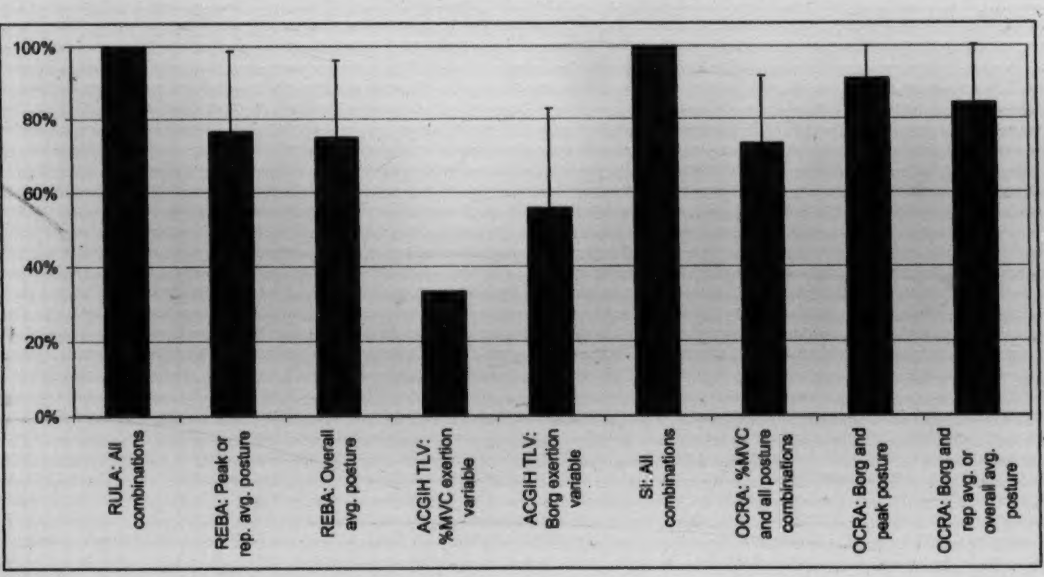
Rep. avg. – Repetition average posture

Table 13-11: OCRA: Effect of exertion variable definition

		Intensity component score	
Subject	**Facility**	**MVC**	**Borg**
1	a	0.85	0.45
2	a	0.85	0.45
3	a	0.85	1
4	b	0.85	0.01
5	b	0.85	0.45
6	b	0.85	0.01
7	b	0.85	0.45
8	b	1	0.2
9	c	0.75	0.2
10	c	0.85	0.2
11	c	0.85	0.65
12	c	0.75	0.65
13	d	1	0.01
14	d	0.85	0.01
15	d	0.75	0.65
	Avg.	0.9	0.4
	S.D.	0.07	0.30
	Min.	0.8	0.0
	Max.	1.0	1.0

Figure 13-1: Saw filer performing the primary hammering saws task.

Figure 13-2: Mean risk level as percentage of maximum by risk assessment method.



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Chapter 14 – Comparison of ergonomic risk assessments in a high risk repetitive sawmill occupation: trim saw operator

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14.1 Introduction

In 2003 a review of Workers Compensation Board claims revealed the tremendous impact of musculoskeletal injuries (MSI) in the sawmill industry of Alberta, Canada (Jones and Kumar 2004a). MSIs accounted for 33% of total time lost due to claim and 38% of the total claims cost from 1997 to 2002. The body region most often affected was the upper extremity which accounted for 1698 claims. The impact of MSIs on the sawmill industry has made their prevention a priority of industrial health and safety initiatives. Evidence of a causal association between physical exposures and incidence of MSI exists and as a result prevention efforts have focused on the identification of problem exposures (US Department of Health and Human Services 1997). Specific cause-effect relationships between physical exposures and MSI are not available and as a result the practice of identifying problem exposures relies on international guidelines applied through ergonomic risk assessment techniques. Unfortunately little agreement exists between authors as to the best method of identifying exposures of concern and the relative role of the exposures considered (Jones and Kumar 2004b). Very few studies are currently available which examine the properties of the ergonomic risk assessments currently being used to direct prevention initiatives in industry. A key issue affecting our ability to reliably examine the properties of ergonomic risk assessments in the past has been the lack of accurate and reliable workplace exposure information. Studies have now documented the large measurement error resulting from exposure information being collected primarily by observation

(Lowe 2004). Reliable tools capable of quantifying exposure information are now available and as a result studies seeking to describe and examine the properties of commonly used ergonomic risk assessments may proceed. Currently there are very few studies which seek to compare the results of multiple risk assessments in the same occupation (Drinkaus et al. 2003, Bao et al. 2006). There is also an absence of research examining the ability of the risk assessment methods to identify differing levels of risk between facilities which have demonstrated differing incidence rates.

The availability of quantified exposure information allows multiple definitions of the exposures variables considered by the risk assessment methods to be applied. No studies could be located which sought to examine the impact of posture and exertion variable definition on risk assessment component and output scores. For these reasons this study seeks to: 1) compare the results of 5 commonly used ergonomic risk assessment methodologies, 2) examine the ability of the different methodologies to differentiate between facilities reporting different incidence rates and 3) examine the effect of 3 posture and 2 exertion variable definitions on the component and risk output scores of the 5 risk assessment methodologies examined. The risk assessment methods compared in this study are the: Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), the quantitative version of the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV), the Strain Index (SI), and the concise exposure index (OCRA) (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005). Risk assessment methods used in this study were selected based on semi objective criteria. All risk assessment methods considered for inclusion in this study generate an output which may be used to prioritize jobs and problem exposures for intervention. There is presently little literature examining the psychometric properties of ergonomic risk assessments individually. Similarly there is a paucity of literature examining the comparability of multiple risk assessment methods. Due to the lack of literature examining ergonomic risk assessment methods selection of methods to be compared in these studies based on an objective decision matrix was not possible. Methods used in these studies were selected based upon their common use in industrial MSI prevention initiatives. Each methods risk output has been broken into two scores; risk level and risk index. Risk index in this study refers to the risk assessments' raw score output before that score is grouped and interpreted. Risk levels refer to the groupings of risk index scores which are interpreted into action levels etc. by the authors.

The trim-saw operator was chosen for further analysis in this study based on the high number of upper extremity MSIs recorded in the position during the 5 years of review. Incidence rates in the trim saw operator ranged from 0.17 to 0.77 per person year worked in the facilities examined.

14.2 Methods

14.2.1 Occupation identification

Deriving incidence rates for the trim saw position using compensation information was not possible given information describing the complete work force was not available (Jones et al. 2004a). For this reason the occupational health records of four sawmill facilities were consulted to determine which production positions were commonly associated with injuries of musculoskeletal nature to the upper extremity and the trim saw position was selected.

14.2.2 Task description

The trim-saw operator is responsible for sorting and positioning boards which have been cut into width dimension before the dimensional lumber enters the trim-saw where it will be cut into length dimension. Dimensional lumber arriving at the trim-saw operator position must be frequently turned to position the round side or "wane" superiorly. Turning boards is the primary task of the trim-saw operator however, he/she may also be required to push, pull and lift boards (position boards) to cause them to fall to conveyors below. Figure 14-1 depicts the primary board turning task of the trim-saw operator.

14.2.3 Subject selection

Male and female workers presently performing the trim-saw position ages 18-65 were recruited at the four sawmill facilities studied. Subjects were excluded from the study if they reported: injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University Health Research Ethics Board. 33 male subjects volunteered to take part in the study out of the population of 33 (100% participation rate). Complete data sets enabling further analysis were collected for 29 subjects.

14.2.4 Data collection

14.2.4.1 Motion Data acquisition

Motion at the wrist was assessed using two pre-calibrated electrogoniometers placed on the wrist and forearm reported by the subjects as used primarily to turn boards as described in part 1 of this series (Jones and Kumar 2006).

14.2.4.1.1 Posture: Postures required to perform the trim saw operator position were defined based on three criteria. The peak excursion was defined as the maximum excursion observed during the entire sample in the respective plane of motion (e.g. flexion or extension). The peak excursion represents the maximum excursion observed and may not have taken place during a repetition of the primary task (turning boards). The repetition average posture was defined by randomly selecting 10 repetitions (board turns), recording the maximum deviation in the plane of interest (e.g. radial and ulnar deviation), and averaging the values in each subject. Finally, the overall average posture reflects the average value observed considering all motion taking place in the defined plane of motion during the sample. In the cases where body regions other than the forearm and wrist are considered (REBA, RULA, OCRA) only the postures of the forearm and wrist vary from peak excursions in the posture variable comparisons.

14.2.4.1.2 Duty cycle: The percentage of the sample where the worker was active as opposed to inactive was determined by defining periods of inactivity as those periods greater than 1.2 seconds during which there is less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force application. Duty cycle was defined by dividing the active component of the sample by the total sample time and multiplying the value by 100.

14.2.4.1.3 Frequency: Repetitions performed during the sample were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees (setting observed to best differentiate between repetitions of primary board turn task) at the proximal radio-ulnar joint (pronation/supination). Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used.

14.2.4.2 Exertion data acquisition

14.2.4.2.1 Percentage of maximum voluntary contraction: Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary and job simulated exertions as described in part one of this series (Jones and Kumar 2006). The average value resulting from the muscles assessed during the job simulated flexion trial and the job simulated pronation trial were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the task components (flexion and pronation). The task components were then averaged to derive %MVC required to perform the primary (board turn) task.

14.2.4.2.2 Psychophysical measure of exertion. Following data collection during job performance workers were asked whether; "during the cycle were there job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the exertions required to perform the actions from one to ten using the Borg CR-10 scale (Borg 1982). Borg ratings were then averaged and used in the ACGIH TLV, SI and OCRA assessments.

14.2.4.2.3Dynamic force applied. Dynamic forces required were used as the exertion variable in the RULA and REBA methods. Dynamic force required to turn the representative board was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. The inertial component of the force required was calculated using the average acceleration recorded.

14.2.5 Data Analysis

Non parametric statistics were used in this study to examine whether statistically significant differences existed between distributions of interest. Non parametric statistics were selected given the assumptions of corresponding parametric statistics (e.g. normality of distribution, equality of variance, large sample sizes) could not be met. The non-parametric Kruskal-Wallis H test (alpha level 0.05) was used to determine if significant differences existed between facilities on risk assessment output scores (component, combined component, risk index, risk level). The Wilcoxin W test (alpha level of .05) was used to test whether significant differences existed between risk assessment scores derived using alternate posture and exertion variable definitions. Mean and not median values are used as measures of central tendency in this study. The measure of central tendency most sensitive to the distribution as a whole (including outliers) was selected given the variability of scores within populations of at-risk workers has not previously been described.

14.2.6 Risk assessment methods

Risk indexes were calculated according to the primary literature describing their application (McAtamney 1993, Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, Hignett et al. 2000, University of Michigan 2005).

14.3 Results

14.3.1 Incidence of upper extremity musculoskeletal injury

Alberta Workers Compensation Board data indicated an average 148 successful claims were incurred annually across the 6 years examined (1997-2002) in the occupation groups containing the trim saw operator position. Incidence rates in the trim saw position calculated based on person year estimates from the four facilities averaged 0.17 (facility A), 0.77 (facility B), 0.60 (facility C) and 0.22 (facility D) recordable musculoskeletal upper extremity incidents per person year in the period examined.

14.3.2 Subject characteristics

The average age of subjects was 31 years (S.D. 8.2 years), average height of subjects was 180 cm (S.D. 6.7 cm), and average weight of subjects was 88.1 kg. (S.D. 12.9 kg.). Average work experience at the trim-saw position at time of assessment was

3.5 years (S.D. 4.1 yrs.). Only average height of the subjects was significantly different (p<.05) across the facilities assessed (maximum differences in mean height between facilities was 10.2 cm.).

14.3.3 Risk assessment methods

Mean risk level assigned by risk assessment method as a percentage of maximum is illustrated for the reader in figure 14-2.

14.3.3.1 RULA

14.3.3.1.1 Between facility comparisons: RULA risk output scores were not sensitive to inter-facility differences in risk of upper extremity MSI. RULA posture component scores for the neck and legs as well as force scores for the trunk and upper extremity were sensitive to inter facility differences (p<.01). As postures of the neck and legs were recorded via observation the sensitivity of the RULA assessment to actual differences in postures based on quantified information cannot be assessed. The RULA force component score was sensitive to differences in upper extremity required dynamic force between facility A and the other facilities assessed. The RULA force cut point of 10 kg. was met by facility A workers and not the other facilities examined resulting insignificantly higher force scores. Despite the sensitivity of certain component scores to inter facility differences risk output scores were not sensitive indicating the RULA assessment was not able to detect differences in risk between facilities. Table 14-1 describes the RULA scores calculated with dynamic force and peak postures.

14.3.3.1.1 Within methodology comparisons: Effect of varying wrist and forearm posture variable definition: Substituting repetition average or overall average forearm and wrist postures for peak postures resulted in significantly different combined upper extremity posture scores (p<.05) but had no effect on risk output. The RULA assessment incorporates postures from a number of body regions not assessed by quantified means. Postures in body regions assessed via observation did not vary from peak postures. It is likely that had quantified information allowing repetition average and overall average postures to be calculated be available for these regions risk output scores would have been affected by posture variable definition. Table 14-2 describes the effect of varying posture variable definition on combined upper extremity posture and risk index score.

14.3.3.2 REBA

14.3.3.2.1 Between facility comparisons: REBA risk output scores were not sensitive to inter facility differences in risk of upper extremity MSI. REBA posture component scores specific to the neck and legs were sensitive to inter facility differences however ($p<.05$). As postures of the neck and legs were recorded via observation the sensitivity of the REBA assessment to actual differences in postures based on quantified information cannot be assessed. Despite the sensitivity of certain component scores to inter facility differences risk output scores were not sensitive indicating the REBA assessment was not able to detect differences in risk between facilities. Table 14-3 describes the REBA scores calculated based on dynamic force and peak postures.

14.3.3.2.2 Within methodology comparisons: Effect of varying wrist and forearm posture variable definition: Substituting overall average forearm and wrist postures for either peak or repetition average postures resulted in significantly different combined upper extremity posture scores ($p<.05$) but had no effect on risk output scores. Substituting repetition average posture for peak postures had no effect on combined upper extremity postures scores. Substituting overall average postures for either peak or repetition average postures reduced combined upper extremity scores by an average of 13% in 4 of 29 subjects. Our results indicate that varying posture definition had no effect on risk output scores. Repetition average and overall average postures were only available for the forearm and wrist however as quantified posture information was collected for these body regions only. It is possible that had quantified posture information been available for the other body regions considered by the REBA assessment varying posture definition may have had a significant effect on REBA risk output. Table 14-4 describes the impact of posture variable on combined upper extremity posture score and risk index.

14.3.3.3 ACGIH TLV for mono-task hand work

14.3.3.3.1 Between facility comparisons: ACGIH TLV risk output was not sensitive to differing levels of upper extremity MSI risk between facilities. ACGIH TLV %MVC and

Hand Activity Level (HAL) component scores did differentiate between facilities however (p<.05). Significant differences were observed in both %MVC required (p<.05) and the frequency variables consider in generating the HAL score (p<.05) as described by Jones and Kumar 2006. Despite the sensitivity of component scores the ACGIH TLV risk output scores were not sensitive to differing risk of upper extremity MSI between facilities.

14.3.3.3.2 Within methodology comparisons: Effect of varying exertion variable definition: Substituting the Borg exertion variable for the %MVC variable resulted in significantly different exertion component scores (p<.001) and risk level scores (p<.001). A risk index is not generated by the ACGIH TLV assessment. Substituting the Borg exertion variable for the %MVC variable resulted in an average increase in exertion component score of 94% in 19 of 29 subjects and decreased the exertion component score by an average of 30% in 3 of 29 subjects. Varying the exertion definition from that generate with the %MVC to that generated with the Borg scale resulted in an increased level of risk assigned to 17 of 29 subjects. In no cases did substitution result in a decreased risk level. Risk level was increased by one risk level in 11 subjects and 2 risk levels in 6 subjects. Our results indicate the ACGIH TLV risk output calculated with the %MVC exertion variable definition are not equivalent to those calculated with the Borg exertion variable. Table 14-5 describes the ACGIH TLV scores calculated based on %MVC and Borg exertion variables.

14.3.3.4 Strain index

14.3.3.4.1 Between facility comparisons: SI risk output was not sensitive to inter facility differences in risk of upper extremity MSI. Both the intensity and duration of task components detected significant differences between facilities assessed however (p<.05). Significant differences in %MVC and hours spent performing the primary task per day was reported by Jones and Kumar (submitted to Human Factors 2006). Table 14-6 describes the SI scores calculated with the %MVC exertion variable and peak postures.

14.3.3.4.2 Within methodology comparisons: Effect of varying hand/wrist posture variable definition: Significant differences in posture component scores and risk index scores resulted from varying posture variable definition (p<.0001). Varying posture variable definition had no effect on risk level scores. Substituting repetition average forearm and wrist postures for peak postures resulted in an average decrease in risk index scores of 38% in 26 of 29 subjects. Substituting overall average forearm and wrist postures for peak postures resulted in an average risk index reduction of 61% in 29 of 29 subjects. Finally substituting overall average for repetition average postures resulted in an average risk index reduction of 45% in 26 of 29 subjects. These results indicate varying posture definition has a significant impact on SI risk index scores in 100% of subjects. Table 14-7 describes the impact of posture variable definition on posture component score and risk index.

14.3.3.4.3 Within methodology comparisons: Effect of varying exertion variable definition: Substituting the Borg exertion variable for the %MVC exertion variable resulted in significantly different exertion component and risk index scores (p<.01). Substituting the Borg exertion variable for the %MVC variable resulted in an average risk index score increase of 81% in 16 of 29 workers. These findings indicate the Borg and %MVC exertion variable definitions result in significantly different risk index scores in the majority of subjects and are therefore not comparable. Table 14-8 describes the impact of exertion variable definition on intensity component score and risk index.

14.3.3.5 OCRA

14.3.3.5.1 Between facility comparisons: OCRA risk index scores were sensitive to inter facility differences in risk of upper extremity MSI (p<.05). The following OCRA component scores were also sensitive to inter facility differences; intensity level defined by %MVC (p<.05), hours of recovery (p<.05), and minutes spent performing the task per day (p<.01). Significant differences in %MVC and hours spent performing the primary task per day was reported by (Jones and Kumar 2006, submitted to Human Factors). Table 14-9 describes the OCRA scores calculated with the %MVC exertion variable and peak postures.

14.3.3.5.2 Within methodology comparisons: Effect of varying hand/wrist posture variable definition: Varying definition of the posture variable resulted in significantly different posture component and risk index scores (p<.001) but had no effect on risk level scores. Substituting repetition average forearm and wrist postures for peak postures reduced risk index scores by an average of 30% in 23 of 29 subjects. Substitution overall average forearm and wrist postures for peak postures resulted in an average risk index score reduction of 34% in 28 of 29 subjects. Finally, substituting overall average postures for repetition average postures reduced risk index scores by an average of 17% in 14 of 29 subjects. These results indicate varying posture definition has a significant impact on SI risk index scores in 98% of subjects. Posture variable definitions are therefore not comparable and may not be used interchangeably. Table 14-10 describes the impact of posture variable definition on posture component score and risk index.

14.3.3.5.3 Within methodology comparisons: Effect of varying exertion variable definition: Substituting the Borg exertion variable for the %MVC exertion variable resulted in significantly different exertion component and risk index scores ($p<.01$). Substituting the Borg exertion variable for the %MVC variable increased risk index scores by an average of 84% in 20 of 29 subjects and reduced risk index scores by an average of 132% in 5 of 29 subjects. These findings indicate the Borg and %MVC exertion variable definitions result in significantly different risk index scores in 86% of subjects and are therefore not comparable. Table 14-11 describes the impact of exertion variable definition on exertion component score and risk index.

14.4 Discussion

14.4.1 Sensitivity of risk assessment methods to facility and worker assessed

Median risk level assigned by all the risk assessment methods examined (with the exception of the ACGIH TLV calculated with %MVC) indicates there is a level of risk of MSI associated with performance of the trim saw operator position. In no case was the risk level assigned by the methods able to differentiate between facilities. This is an important finding as seemingly significant differences in past incidence of upper extremity MSI exist between facilities. Incidence of reportable upper extremity events per person year worked in the trim saw operator position ranged from 0.17 to 0.77. Differing incidence rates suggests that physical exposures related to incidence of MSI may be significantly different between the facilities and may be at least in part to blame for the increased rates of incidence. Should this be the case and significantly different exposures between facilities within the same job be present assessments are needed which are able to identify the problem exposures in order to direct meaningful intervention. As risk levels assigned by the methods were not sensitive to differences between facilities evaluators must look further into the methodologies to identify component and risk output scores (risk index) sensitive to inter facility differences to direct intervention. Each of the methodologies examined was observed to be sensitive to worker technique. The sensitivity of the methodologies to worker technique suggests a number of workers must be assessed before a facility specific representative risk will be obtained. If the methodologies are sensitive to worker technique and a representative risk for the facility was collected it is reasonable to hypothesize that aspects of the risk assessment methodology may be sensitive to differences in exposures present between facilities. Quantified measurement of physical exposures in this population has identified significant differences in a number of exposure variables (Jones and Kumar 2006). Aspects of every methodology examined were sensitive to inter facility differences. In most cases only component or combined component scores were sensitive to differences but in one case (the OCRA assessment) the risk output of the model was sensitive to inter facility differences. The sensitivity of component scores to inter facility differences suggests that the number of scoring categories present in the component was sufficient to detect differences. The sensitivity of component scores does not speak to the risk assessments ability to assign the relative importance of that variable in causation of MSI. Evidence that the correct relative role of the physical exposures has been assigned is only present for the OCRA assessment in which the integrated risk output of the model has been shown to be sensitive to inter facility differences. Methodologies able to correctly assign the relative role of the exposure variables considered in an integrated model of MSI causation upon which they are based should be best able to direct meaningful intervention. In this study the OCRA assessment correctly identified an increased risk present in facility D (0.22) over facility A (0.17) but incorrectly indicated a greater risk in facility D than facility B (0.77) and facility C (0.60) (considering risk levels assigned). Two important factors may explain this difference; first, significantly different risk index scores were present in facility D because of the time spent performing the trim saw operator position. 9 or more hours spent performing the trim saw operator position per shift was reported by 5 of 6 subjects assessed resulting in OCRA risk index scores of 0.

Had a multiplier other than 0 been applicable significant differences may not have been observed. Second, incidences of upper extremity musculoskeletal injuries were recorded with unique systems in each of the facilities examined. While each facility does record upper extremity MSIs resulting in first aid and greater severity injuries the lack of a standardized surveillance system between facilities limits our ability to draw conclusion based on the grouped data to suggestive. Our findings suggest that the OCRA assessment was best able to differentiate between facilities however the limitations of the incidence data upon which this suggestion is based prevent firm conclusions from being drawn.

14.4.2 Maximizing risk assessment sensitivity

The sensitivity of the risk assessment scores ultimately impacts the utility of the methodology as a tool for directing prevention initiatives to problem exposures. Two factors were observed to govern the sensitivity of the tools to inter worker and inter facility differences. First the width and number of scoring categories present for each component considered by the methodology may either increase of decrease the sensitivity of the method. For example the less variability between subjects in upper extremity exertion scores in the REBA and RULA assessment (4 categories) than the ACGIH TLV, SI or OCRA assessments (10 categories) results in less variability in the RULA and REBA assessments. Wide scoring categories previously made necessary because of inaccuracy due to observation are no longer necessary as quantitative tools for workplace exposure measurement are now available. Secondly, the structure of the model by which the exposure variables are integrated impacts the sensitivity of the method. Less variability may be expected from the RULA, REBA, and ACGIH TLV assessments as the ordinal risk indexes are generated by tabular "look-up" methods. In the cases of the SI and OCRA assessments interval level risk indexes are derived by multiplying component scores. Greater sensitivity is achieved by the multiplicative approach of the SI and OCRA methods than the tabular "look-up" method of the RULA, REBA, and ACGIH TLV method.

14.4.3 Effect of varying posture and exertion variable definition on risk output

The availability of quantified exposure data allows the evaluator the ability to apply multiple definitions to exposure variables considered by the risk assessment methodologies used. Definition of forearm and wrist posture was observed to significantly affect component or combined component scores in every methodology considering posture in the majority of subjects assessed. In the cases of the SI and OCRA methods risk output scores were also significantly different and resulted in average risk index score reductions of up to 61% when overall average postures were substituted for peak postures. These findings indicate that in the cases of the SI and OCRA methods posture definitions may not be used interchangeably. Conclusions regarding the impact of posture variable definition on the risk output of the RULA and REBA assessments may not be made in this study. RULA and REBA assessments consider many more body regions than the forearm and wrist and data enabling multiple posture definitions to be applied was only available for the forearm and wrist. Definition of the exertion variable was also observed to significantly impact exertion component scores and risk output. Primary literature describing the ACGIH TLV, SI and OCRA methods provides scales by which exertion information collected via electromyography (%MVC) or the Borg scale may be used to derive the exertion variable (Moore et al. 1995, Colombini 1998, Grieco 1998, Occhipinti 1998, University of Michigan 2005). Our results indicate that substituting the Borg exertion variable for the %MVC variable resulted in significantly different component and risk output scores in the majority of subjects affecting scores by as much as 132%. Our results indicate that the %MVC exertion variable and Borg exertion variable are not comparable in the ACGIH TLV, SI or OCRA assessments as they have been defined here.

14.5 Conclusion

Median risk level scores of all methods examined, with the exception of the ACGIH TLV calculated with %MVC, identified a level of risk associated with the trim saw operator position. Risk level scores were not observed to vary between facilities assessed despite data indicating that differing levels of risk existed between facilities. This finding suggests industrial prevention efforts must interpret risk index and component scores to identify problem exposures. Suggestive evidence was found that the OCRA assessment was best able to assign the relative role of the physical exposures of concern in an integrated risk output and therefore best able to identify problem exposures. Further studies of the association between incidence of upper extremity MSI, risk assessment output and the impact of exposure variable definition are needed based on standardized surveillance information.

14.6 Acknowledgement

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Table 14-1: RULA scores calculated with peak postures

		Component scores							Combined component scores								Risk output scores	
		Posture Trunk/Neck/Legs			Posture Upper extremity				Trunk/Neck/Legs				Upper extremity				Risk index	Risk level
Subject	Facility	Neck	Trunk	Legs	Upper arm	Lower arm	Wrist	Wrist twist	Posture	Muscle	Force	Score D	Posture	Muscle	Force	Score C	Grande score	Risk Level
1	a	2	5	2	5	3	4	1	7	1	3	11	7	1	3	11	7	4
2	a	1	5	2	4	3	4	2	6	1	3	10	6	1	3	10	7	4
3	a	1	3	2	3	3	4	2	4	1	3	8	5	1	3	9	7	4
4	a	1	5	2	5	3	4	1	6	1	3	10	7	1	3	11	7	4
5	a	2	5	2	5	2	4	1	7	1	3	11	7	1	3	11	7	4
6	a	2	5	2	4	3	4	1	7	1	3	11	6	1	3	10	7	4
7	a	2	4	2	5	3	4	2	5	1	3	9	8	1	3	12	7	4
8	a	2	5	2	4	3	4	1	7	1	3	11	6	1	3	10	7	4
9	a	2	5	2	5	3	4	1	7	1	3	11	7	1	3	11	7	4
10	a	6	5	2	6	3	4	1	9	1	3	13	9	1	3	13	7	4
11	b	3	3	2	5	3	4	1	5	1	2	8	7	1	2	10	7	4
12	b	2	3	2	5	3	4	1	5	1	2	8	7	1	2	10	7	4
13	b	1	5	2	4	3	4	1	6	1	2	9	6	1	2	9	7	4
14	b	5	5	1	6	3	4	1	8	1	2	11	9	1	2	12	7	4
15	b	3	5	2	5	3	4	1	7	1	2	10	7	1	2	10	7	4
16	c	3	2	1	4	3	4	1	3	1	2	6	6	1	2	9	7	4
17	c	4	5	1	5	3	4	1	7	1	2	10	7	1	2	10	7	4
18	c	6	4	1	4	3	4	1	8	1	2	11	6	1	2	9	7	4
19	c	6	5	1	5	3	4	1	9	1	2	12	7	1	2	10	7	4
20	c	5	4	1	5	3	4	1	8	1	2	11	7	1	2	10	7	4
21	c	6	5	1	6	3	4	2	9	1	2	12	9	1	2	12	7	4
22	c	5	3	1	4	2	4	1	7	1	2	10	5	1	2	8	7	4
23	c	3	3	1	4	2	4	1	4	1	2	7	5	1	2	8	7	4
24	d	3	4	2	5	3	4	1	6	1	2	9	7	1	2	10	7	4
25	d	3	4	2	5	3	4	1	6	1	2	9	7	1	2	10	7	4
26	d	3	4	2	5	3	4	1	6	1	2	9	7	1	2	10	7	4
27	d	3	5	2	5	2	4	2	7	1	2	10	7	1	2	10	7	4
28	d	3	4	2	5	3	4	1	6	1	2	9	7	1	2	10	7	4
29	d	3	4	2	5	2	4	1	6	1	2	9	7	1	2	10	7	4
	Avg.	3.1	4.3	1.7	4.8	2.8	4.0	1.2	6.5	1.0	2.3	9.8	6.8	1.0	2.3	10.2	7.0	4.0
	S.D.	1.60	0.88	0.47	0.69	0.38	0.00	0.38	1.48	0.00	0.48	1.56	1.04	0.00	0.48	1.14	0.00	0.00
	Min.	1	2	1	3	2	4	1	3	1	2	6	5	1	2	8	7	4
	Max.	6	5	2	6	3	4	2	9	1	3	13	9	1	3	13	7	4

Table 14-2: RULA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	7	7	7	7	7	7
2	a	6	6	6	7	7	7
3	a	5	5	5	7	7	7
4	a	7	7	7	7	7	7
5	a	7	7	7	7	7	7
6	a	6	6	5	7	7	7
7	a	8	7	7	7	7	7
8	a	6	6	5	7	7	7
9	a	7	7	7	7	7	7
10	a	9	9	9	7	7	7
11	b	7	7	7	7	7	7
12	b	7	7	7	7	7	7
13	b	6	6	6	7	7	7
14	b	9	9	9	7	7	7
15	b	7	7	7	7	7	7
16	c	6	6	6	7	7	7
17	c	7	7	7	7	7	7
18	c	6	6	5	7	7	7
19	c	7	7	7	7	7	7
20	c	7	7	7	7	7	7
21	c	9	9	9	7	7	7
22	c	5	5	4	7	7	7
23	c	5	5	5	7	7	7
24	d	7	7	7	7	7	7
25	d	7	7	7	7	7	7
26	d	7	7	7	7	7	7
27	d	7	7	6	7	7	7
28	d	7	7	7	7	7	7
29	d	7	7	6	7	7	7
	Avg.	6.8	6.8	6.6	7.0	7.0	7.0
	S.D.	1.04	1.01	1.21	0.00	0.00	0.00
	Min.	5	5	4	7	7	7
	Max.	9	9	9	7	7	7

Rep. avg. – Repetition average posture

Table 14-3: REBA index calculated with peak postures

		Component scores						Combined component scores								Risk output scores	
		Trunk/Neck/Legs			Upper extremity			Trunk/Neck/Legs			Upper extremity			Multiple body part		Risk index	Risk level
Subject	Facility	Trunk	Neck	Legs	Upper arm	Lower arm	Wrist	Posture total	Force	Score A	Posture Total	Grip	Score B	Score C	Activity score	Grand score	Risk Level
1	a	4	2	2	5	2	3	6	2	8	8	1	9	10	2	12	4
2	a	4	1	2	4	2	3	5	2	7	7	1	8	10	2	12	4
3	a	3	1	2	3	1	3	4	2	6	5	1	6	8	1	9	3
4	a	4	1	2	5	2	3	5	2	7	8	1	9	10	2	12	4
5	a	4	2	2	5	1	3	6	2	8	8	1	9	10	2	12	4
6	a	4	2	2	4	2	3	6	2	8	7	1	8	10	2	12	4
7	a	3	2	2	5	2	3	5	2	7	8	1	9	10	2	12	4
8	a	4	2	2	4	1	3	6	2	8	5	1	6	10	2	12	4
9	a	4	2	2	5	2	3	6	2	8	8	1	9	10	2	12	4
10	a	4	3	2	6	2	3	7	2	9	9	1	10	12	2	14	4
11	b	3	2	2	5	2	3	5	2	7	8	1	9	10	2	12	4
12	b	3	2	2	5	1	3	5	2	7	8	1	9	10	2	12	4
13	b	4	1	2	4	1	3	5	2	7	5	1	6	9	1	10	3
14	b	4	3	1	6	2	3	6	2	8	9	1	10	11	2	13	4
15	b	4	2	2	5	2	3	6	2	8	8	1	9	10	2	12	4
16	c	2	2	1	4	2	3	3	2	5	7	1	8	8	2	10	3
17	c	4	3	1	5	2	3	6	2	8	8	1	9	10	2	12	4
18	c	3	3	1	4	2	3	5	2	7	7	1	8	10	2	12	4
19	c	4	3	1	5	2	3	6	2	8	8	1	9	10	2	12	4
20	c	3	3	1	5	2	3	5	2	7	8	1	9	10	2	12	4
21	c	4	3	1	6	2	3	6	2	8	9	1	10	11	2	13	4
22	c	3	3	1	4	1	3	5	2	7	5	1	6	9	2	11	4
23	c	3	2	1	4	1	3	4	1	5	5	1	6	7	1	8	3
24	d	3	2	2	5	2	3	5	2	7	8	1	9	10	2	12	4
25	d	3	2	2	5	2	3	5	2	7	8	1	9	10	2	12	4
26	d	3	2	2	5	2	3	5	2	7	8	1	9	10	2	12	4
27	d	4	2	2	5	2	3	6	2	8	8	1	9	10	2	12	4
28	d	3	2	2	5	2	3	5	2	7	8	1	9	10	2	12	4
29	d	3	2	2	5	1	3	5	2	7	8	1	9	10	2	12	4
	Avg.	3.5	2.1	1.7	4.8	1.7	3.0	5.3	2.0	7.3	7.4	1.0	8.4	9.8	1.9	11.7	3.9
	S.D.	0.57	0.64	0.47	0.69	0.45	0.00	0.81	0.19	0.88	1.24	0.00	1.24	0.93	0.31	1.16	0.35
	Min.	2	1	1	3	1	3	3	1	5	5	1	6	7	1	8	3
	Max.	4	3	2	6	2	3	7	2	9	9	1	10	12	2	14	4

Table 14-4: REBA effect of varying posture variable definitions on combined upper extremity posture and risk index scores

		Combined upper extremity posture scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	8	8	8	12	12	12
2	a	7	7	7	12	12	12
3	a	5	5	5	9	9	9
4	a	8	8	8	12	12	12
5	a	8	8	8	12	12	12
6	a	7	7	6	12	12	12
7	a	8	8	8	12	12	12
8	a	5	5	5	12	12	12
9	a	8	8	8	12	12	12
10	a	9	9	9	14	14	14
11	b	8	8	8	12	12	12
12	b	8	8	7	12	12	12
13	b	5	5	5	10	10	10
14	b	9	9	9	13	13	13
15	b	8	8	8	12	12	12
16	c	7	7	7	10	10	10
17	c	8	8	8	12	12	12
18	c	7	7	6	12	12	11
19	c	8	8	8	12	12	12
20	c	8	8	8	12	12	12
21	c	9	9	9	13	13	13
22	c	5	5	5	11	11	11
23	c	5	5	5	8	8	8
24	d	8	8	8	12	12	12
25	d	8	8	8	12	12	12
26	d	8	8	8	12	12	12
27	d	8	8	8	12	12	12
28	d	8	8	8	12	12	12
29	d	8	8	7	12	12	12
	Avg.	7.4	7.4	7.3	11.7	11.7	11.7
	S.D.	1.24	1.24	1.28	1.16	1.16	1.17
	Min.	5	5	5	8	8	8
	Max.	9	9	9	14	14	14

Rep. avg. – Repetition average posture

Table 14-5: ACGIH TLV scores calculated with %MVC and Borg exertion variables

		Component scores			Risk level	Risk level
Subject	Facility	% MVC exertion score	Borg exertion score	Hand Activity Level	MVC	Borg
1	a	5	4	3	2	2
2	a	3	4	2	1	1
3	a	3	8	4	1	3
4	a	4	6	4	2	3
5	a	5	4	3	2	2
6	a	3	3	3	1	1
7	a	4	4	1	1	1
8	a	4	5	2	1	2
9	a	4	9	3	2	3
10	a	4	4	3	2	2
11	b	2	5	3	1	2
12	b	3	5	3	1	2
13	b	2	6	4	1	3
14	b	3	6	4	1	3
15	b	2	4	4	1	2
16	c	5	6	4	3	3
17	c	4	9	4	2	3
18	c	3	5	3	1	2
19	c	5	5	4	3	3
20	c	4	8	2	1	3
21	c	3	3	4	1	1
22	c	5	7	3	2	3
23	c	3	3	2	1	1
24	d	2	6	4	1	3
25	d	4	5	4	2	3
26	d	2	5	4	1	3
27	d	2	1	4	1	1
28	d	3	4	4	1	2
29	d	5	5	4	3	3
	Avg.	3.5	5.1	3.3	1.5	2.3
	S.D.	1.06	1.83	0.85	0.69	0.80
	Min.	2	1	1	1	1
	Max.	5	9	4	3	3

Table 14-6: Strain index scores calculated with peak postures and %MVC

Component scores								Risk output scores	
Subject	Facility	Intensity (%MVC)	Duration	Efforts/min	Posture	Speed	Duration	Index score	Risk level
1	a	6	1	3	3	1.5	1	81.0	3
2	a	6	1	3	3	1.5	1	81.0	3
3	a	6	1	3	3	1.5	1	81.0	3
4	a	6	1	3	3	1.5	1	81.0	3
5	a	6	1	3	3	1.5	0.75	60.8	3
6	a	3	1	2	3	1.5	0.75	20.3	3
7	a	6	0.5	1.5	3	1.5	0.25	5.1	2
8	a	6	1	1.5	3	1.5	0.75	30.4	3
9	a	6	1	3	3	1.5	1	81.0	3
10	a	6	1	3	3	1.5	1	81.0	3
11	b	3	1	3	2	1.5	0.75	20.3	3
12	b	3	1	3	2	1.5	0.75	20.3	3
13	b	3	1.5	3	3	1.5	0.75	45.6	3
14	b	6	1	3	3	1.5	0.75	60.8	3
15	b	3	1	3	2	1.5	0.75	20.3	3
16	c	9	1	3	3	1.5	1	121.5	3
17	c	6	1	3	3	2	1	108.0	3
18	c	3	1	3	3	2	0.25	13.5	3
19	c	6	1	3	3	2	1	108.0	3
20	c	6	1	3	2	1.5	0.75	40.5	3
21	c	6	1	3	3	2	0.75	81.0	3
22	c	6	1	3	3	1.5	0.25	20.3	3
23	c	6	1	1.5	3	1.5	0.75	30.4	3
24	d	3	1	3	3	1.5	1.5	60.8	3
25	d	6	1	3	2	1.5	1	54.0	3
26	d	3	1	3	3	1.5	1.5	60.8	3
27	d	3	1.5	3	3	1.5	1.5	91.1	3
28	d	3	1	3	3	1.5	1.5	60.8	3
29	d	6	1	3	3	1.5	1.5	121.5	3
	Avg.	5.1	1.0	2.8	2.8	1.6	0.9	60.1	3.0
	S.D.	1.62	0.16	0.49	0.38	0.18	0.35	33.64	0.19
	Min.	3	0.5	1.5	2	1.5	0.25	5.0625	2
	Max.	9	1.5	3	3	2	1.5	121.5	3

Table 14-7: Strain index: effect of posture variable definition

		Posture multiplier score			Risk index		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	3	1.5	1	81.0	40.5	27.0
2	a	3	2	1	81.0	54.0	27.0
3	a	3	2	1.5	81.0	54.0	40.5
4	a	3	2	1	81.0	54.0	27.0
5	a	3	1.5	1.5	60.8	30.4	30.4
6	a	3	2	1	20.3	13.5	6.8
7	a	3	2	1	5.1	3.4	1.7
8	a	3	2	1	30.4	20.3	10.1
9	a	3	2	1	81.0	54.0	27.0
10	a	3	2	1	81.0	54.0	27.0
11	b	2	2	1	20.3	20.3	10.1
12	b	2	2	1	20.3	20.3	10.1
13	b	3	2	1	45.6	30.4	15.2
14	b	3	1.5	1.5	60.8	30.4	30.4
15	b	2	1.5	1.5	20.3	15.2	15.2
16	c	3	1.5	1	121.5	60.8	40.5
17	c	3	2	1	108.0	72.0	36.0
18	c	3	1.5	1	13.5	6.8	4.5
19	c	3	2	1	108.0	72.0	36.0
20	c	2	2	1	40.5	40.5	20.3
21	c	3	1.5	1	81.0	40.5	27.0
22	c	3	2	1	20.3	13.5	6.8
23	c	3	2	1	30.4	20.3	10.1
24	d	3	2	1	60.8	40.5	20.3
25	d	2	1.5	1	54.0	40.5	27.0
26	d	3	1.5	1	60.8	30.4	20.3
27	d	3	2	1	91.1	60.8	30.4
28	d	3	2	1	60.8	40.5	20.3
29	d	3	1.5	1	121.5	60.8	40.5
	Avg.	2.8	1.8	1.1	60.1	37.7	22.2
	S.D.	0.38	0.24	0.18	33.64	19.43	11.43
	Min.	2	1.5	1	5.0625	3.375	1.6875
	Max.	3	2	1.5	121.5	72	40.5

Rep. avg. – Repetition average posture

Table 14-8: Strain index: effect of exertion variable definition

		Exertion variable	
Subject	Facility	% MVC	Borg
1	a	6	6
2	a	6	6
3	a	6	13
4	a	6	9
5	a	6	6
6	a	3	3
7	a	6	6
8	a	6	6
9	a	6	13
10	a	6	6
11	b	3	6
12	b	3	6
13	b	3	9
14	b	6	9
15	b	3	6
16	c	9	9
17	c	6	13
18	c	3	6
19	c	6	6
20	c	6	13
21	c	6	3
22	c	6	9
23	c	6	3
24	d	3	9
25	d	6	6
26	d	3	6
27	d	3	1
28	d	3	6
29	d	6	6
	Avg.	5.1	7.1
	S.D.	1.62	3.09
	Min.	3	1
	Max.	9	13

Table 14-9: OCRA index calculated with peak postures and %MVC

		Component scores							Risk output scores	
Subject	Facility	Intensity (%MVC)	Posture	Additional factors total	Hours recovery	Mins/day	Total reps/day	Rec. actions	OCRA Index	Risk level
1	a	0.1	0.6	0.9	0.45	270	6196	196.83	31.48	3
2	a	0.45	0.6	0.9	1	270	4043	1968.3	2.05	2
3	a	0.45	0.6	0.95	0.45	325.2	9816	1126.09	8.72	3
4	a	0.2	0.5	0.9	0.45	270	8331	328.05	25.4	3
5	a	0.1	0.6	0.9	1	238	4808	385.56	12.47	3
6	a	0.45	0.6	0.9	1	216	4053	1574.64	2.57	2
7	a	0.1	0.5	0.9	1	27	292	36.45	8.01	3
8	a	0.35	0.5	0.9	1	238	3072	1124.55	2.73	2
9	a	0.35	0.5	0.9	0.45	270	5852	574.09	10.19	3
10	a	0.35	0.5	0.9	1	270	5201	1275.75	4.08	3
11	b	0.75	0.6	0.9	1	135	2404	1640.25	1.47	2
12	b	0.55	0.6	0.9	1	135	2653	1202.85	2.21	2
13	b	0.75	0.3	0.9	0.8	135	4540	656.1	6.92	3
14	b	0.35	0.5	0.9	0.7	163	4708	539.12	8.73	3
15	b	0.65	0.7	0.95	0.7	162.6	3441	1475.96	2.33	2
16	c	0.01	0.6	0.9	0.1	432	11816	7	1688.39	3
17	c	0.2	0.5	0.9	0.45	324	10921	393.66	27.74	3
18	c	0.65	0.5	0.9	1	27	592	236.93	2.5	2
19	c	0.1	0.5	0.9	0.45	270	7509	164.03	45.78	3
20	c	0.35	0.6	0.8	1	184	2746	927.36	2.96	2
21	c	0.35	0.5	0.8	0.8	135	3673	453.6	8.1	3
22	c	0.1	0.5	0.8	1	27	665	32.4	20.52	3
23	c	0.45	0.6	0.8	1	135	1869	874.8	2.14	2
24	d	0.65	0.5	0.9	0	540	12205	0	0	3
25	d	0.2	0.6	0.9	1	300	7380	972	7.59	3
26	d	0.65	0.5	0.9	0	600	18403	0	0	3
27	d	0.75	0.5	0.9	0	600	20000	0	0	3
28	d	0.45	0.5	0.9	0	600	12619	0	0	3
29	d	0.2	0.5	0.8	0	600	16155	0	0	3
	Avg.	0.381	0.538	0.886	0.648	272.4	6757.3	626.4	66.7	2.7
	S.D.	0.225	0.073	0.042	0.392	173.73	5267.87	591.96	312.09	0.47
	Min.	0.01	0.3	0.8	0	27	292	0	0	2
	Max.	0.75	0.7	0.95	1	600	20000	1968.3	1688.39	3

Table 14-10: OCRA: effect of posture variable definition

		Posture component scores			Risk index scores		
Subject	Facility	Peak	Rep avg.	Overall average	Peak	Rep avg.	Overall average
1	a	0.6	0.6	0.7	31.48	31.48	26.98
2	a	0.6	0.6	0.7	2.05	2.05	1.76
3	a	0.6	0.6	0.7	8.72	8.72	7.47
4	a	0.5	0.6	0.7	25.4	21.16	18.14
5	a	0.6	0.6	0.7	12.47	12.47	10.7
6	a	0.6	0.7	0.7	2.57	2.21	2.21
7	a	0.5	0.7	0.7	8.01	5.72	5.72
8	a	0.5	0.6	0.7	2.73	2.28	1.95
9	a	0.5	0.6	0.7	10.19	8.49	7.28
10	a	0.5	0.7	0.7	4.08	2.91	2.91
11	b	0.6	0.7	0.7	1.47	1.26	1.26
12	b	0.6	0.7	0.7	2.21	1.89	1.89
13	b	0.3	0.6	0.7	6.92	3.46	2.97
14	b	0.5	0.7	0.7	8.73	6.237649	6.237649
15	b	0.7	0.7	0.7	2.33	2.33	2.33
16	c	0.6	0.7	0.7	1688.39	1447.19	1447.19
17	c	0.5	0.6	0.7	27.74	23.12	19.82
18	c	0.5	0.7	0.7	2.5	1.78	1.78
19	c	0.5	0.6	0.7	45.78	38.15	32.7
20	c	0.6	0.7	0.7	2.96	2.54	2.54
21	c	0.5	0.7	0.7	8.1	5.78	5.78
22	c	0.5	0.7	0.7	20.52	14.66	14.66
23	c	0.6	0.6	0.7	2.14	2.14	1.83
24	d	0.5	0.6	0.7	0	0	0
25	d	0.6	0.7	0.7	7.59	6.51	6.51
26	d	0.5	0.6	0.7	0	0	0
27	d	0.5	0.7	0.7	0	0	0
28	d	0.5	0.6	0.7	0	0	0
29	d	0.5	0.7	0.7	0	0	0
	Avg.	0.54	0.65	0.70	66.73	57.05	56.30
	S.D.	0.073	0.051	0.000	312.088	267.536	267.635
	Min.	0.3	0.6	0.7	0	0	0
	Max.	0.7	0.7	0.7	1688.39	1447.19	1447.19

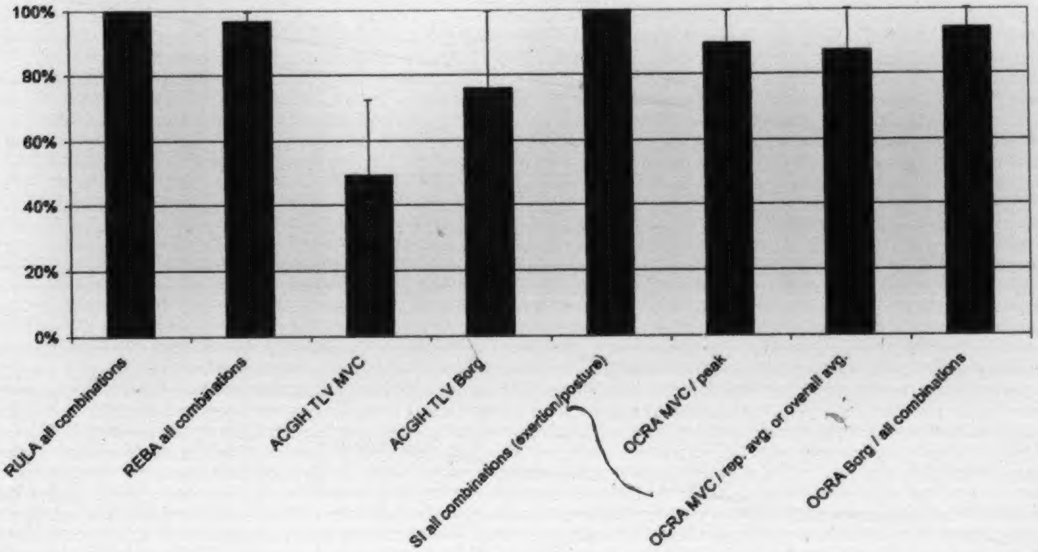
Rep. avg. – Repetition average posture

Table 14-11: OCRA: Effect of exertion variable definition

		Intensity component score	
Subject	**Facility**	**MVC**	**Borg**
1	a	0.1	0.35
2	a	0.45	0.35
3	a	0.45	0.01
4	a	0.2	0.01
5	a	0.1	0.35
6	a	0.45	0.45
7	a	0.1	0.2
8	a	0.35	0.01
9	a	0.35	0.01
10	a	0.35	0.2
11	b	0.75	0.01
12	b	0.55	0.01
13	b	0.75	0.01
14	b	0.35	0.01
15	b	0.65	0.2
16	c	0.01	0.01
17	c	0.2	0.01
18	c	0.65	0.01
19	c	0.1	0.1
20	c	0.35	0.01
21	c	0.35	0.45
22	c	0.1	0.01
23	c	0.45	0.45
24	d	0.65	0.01
25	d	0.2	0.1
26	d	0.65	0.1
27	d	0.75	1
28	d	0.45	0.2
29	d	0.2	0.01
	Avg.	0.381	0.160
	S.D.	0.225	0.225
	Min.	0.01	0.01
	Max.	0.75	1

Figure 14-1: Trim saw operator performing primary (board turn) task.

Figure 14-2: Mean risk level as percentage of maximum by risk assessment method



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Chapter 15 – Comparison of ergonomic risk assessment output in four sawmill jobs

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15.1 Introduction

Industrial musculoskeletal injury prevention initiatives require risk assessment tools which accurately identify jobs at increased risk of injury. Accurate identification of at-risk jobs requires a model of musculoskeletal injury (MSI) causation which considers relevant physical exposures in an integrated framework which assigns the correct relative role to those exposures. Ergonomic risk assessments are based on integrated models of musculoskeletal injury causation which account for the role of physical exposures in the precipitation of musculoskeletal injuries. The description of several ergonomic risk assessments has been published and many of the methods have demonstrated predictive validity (Moore and Garg 1997, Grieco 1998, Massaccesi et al. 2003, Franzblau et al. 2005). Consensus among the authors as to which exposures should be considered and the relative role of the exposures in the causation of musculoskeletal injury has not been reached however (Jones and Kumar 2004a).

Prior to calculating ergonomic risk the evaluator is required to record the physical exposures required to perform the job. Traditionally the assessment of exposure is performed based on observation. A body of evidence is now present which calls into question the ability of observational assessments to accurately record exposures (Lowe 2004, Marshall and Armstrong 2004). Few studies are available which have examined the comparability of risk output derived from multiple ergonomic risk assessments, and no studies are available which have calculated risk based on quantified exposure assessments (Drinkaus et al. 2003, Bao et al. 2006). Given the common use of ergonomic risk assessments in industrial ergonomic initiatives evaluation of the agreement between methods, based on quantified exposure assessments, is of primary importance.

A review of compensation board information performed by Jones and Kumar (2004b) revealed the tremendous impact of upper extremity MSIs on the sawmill industry of Alberta, Canada. As a result of this review a series of field studies were performed in order to quantify the physical exposures required to perform four high risk sawmill occupations (Jones and Kumar 2006,2007a,b,c). The quantified exposure assessments presented by Jones and Kumar (2006,2007a,b,c) were used in this study to calculate five ergonomic risk assessments commonly used to assess risk of upper extremity MSI associated with an industrial job.

The objectives of this study were to: 1) examine the agreement between five upper extremity ergonomic risk assessment methods which have been calculated based on quantitative exposure measures and 2) examine the ability of the methods to identify four at-risk jobs. The five ergonomic risk assessment methods evaluated in this study are the: Rapid Upper Limb Assessment (RULA) (McAtameny and Corlett 1993), Rapid Entire Body Assessment (REBA) (Hignett and McAtamney 1993), the quantitative American Conference of Governmental Industrial Hygienist's Threshold Limit Value for mono-task hand work (ACGIH TLV) (University of Michigan 2005), the Strain Index (Moore and Garg 1997), and the concise exposure index (OCRA) (Grieco 1998, Colombini 1998). All of the ergonomic risk assessment methods compared are focused on the upper extremity with the exception of the REBA assessment. The REBA method was included in this study as the structure of the REBA assessment is only slightly different than that of the RULA assessment which is designed to assess risk of upper extremity MSIs.

15.2 Methods

15.2.1 Subject selection

Workers 18-65 years of age performing four sawmill occupations observed to be associated with upper extremity MSIs were recruited from four sawmill facilities in Alberta, Canada. Ninety three workers volunteered to take part in the study out of the population of 93 (100% participation rate). Complete datasets enabling analysis were collected for 87 subjects. Subjects were excluded from the study if they reported: injury to the upper extremity within the last 12 months, generalized musculoskeletal or neuromuscular problems, or the inability to understand and follow instructions. The experimental protocol was approved by the University Health Research Ethics Board.

15.2.2 Occupation descriptions

Board edger operator (n=14): The board edger position is a repetitive job responsible for sorting boards cut in rough depth dimension immediately after logs have been cut to square dimension and divided into multiple boards. The primary task of the board edger operator is turning boards to position the round side of the board up to enable further processing. Incidence rates in the board edger position calculated based on person year estimates from the facilities examined. There were 0.78 recordable musculoskeletal upper extremity incidents per person year in the period examined (1997 to 2002). The physical exposure required to perform the board edger operator job used to calculate the ergonomic assessments examined are further described by Jones and Kumar (2007a).

Lumber grader (n=29): The lumber grader is responsible for assigning a product grade to each piece of dimensional lumber leaving a sawmill. The primary task of the lumber grader is to turn boards to enable inspection and grade assignment. Incidence rates in the lumber grader position calculated based on person year estimates from the facilities examined averaged 0.19 recordable musculoskeletal upper extremity incidents per person year in the period examined (1997 to 2002). The physical exposure required to perform the lumber grader job used to calculate the ergonomic assessments examined are further described by Jones and Kumar (2007c).

Saw filer (n=15): The primary function of the saw filer position is to maintain the condition of the round saws, band saws, and chipper blades (knives). The primary task of the saw filer is hammering of the round saw blades to correct imperfections and tension the blade. Incidence rates in the saw filer position calculated based on person year estimates from the facilities examined averaged 0.43 recordable musculoskeletal upper extremity incidents per person year in the period examined (1997 to 2002). The physical exposure required to perform the saw-filer job used to calculate the ergonomic assessments examined are further described by Jones and Kumar (2006).

Trim saw operator (n=29): The trim-saw operator is responsible for sorting and positioning boards which have been cut into width dimension before the dimensional lumber enters the trim-saw to be cut into length dimension. The primary task of the trim-saw operator is turning boards to position the round side of the board up to enable further processing. Incidence rates in the trim-saw position calculated based on person year estimates from the facilities examined averaged 0.44 recordable musculoskeletal upper extremity incidents per person year in the period examined (1997 to 2002). The physical exposure required to perform the trim-saw operator job used to calculate the ergonomic assessments examined are further described by Jones and Kumar (2007b).

15.2.3 Exposure assessment

Motion and posture data acquisition: Motion and posture required to perform the jobs assessed were recorded during actual job performance on the production line. Five minutes of job performance of board edger operators, lumber graders and trim saw operators and 15 minutes of the job performance of the saw-filers was recorded. Only the upper extremity used to perform the primary job task was assessed. A Biometrics bi-axial SG-65 and uni-axial Q-150 electrogoniometer were applied to the task dominant upper extremity as per the users' manual recommendations (Biometrics 2002). Prior to beginning data collection the subjects were asked to position their elbow at 90 degrees, their forearm in mid position (thumb positioned superiorly), and wrist in neutral position (0 degrees in the plane of flexion/extension and radial/ulnar deviation) while the electrogoniometers were zeroed. Angular displacement was recorded in 3 planes (X,Y,Z) with a bi-axial and uni-axial Biometrics ™ electrogoniometer at 200 Hz. Postures and frequencies required to perform the job were determined through analysis of the recorded wave forms with the Biometrics Data link analysis software.

Exertion: The Strain Index, quantitative ACGIH TLV and OCRA assessments provide scales which allow exertion to be defined either by psychophysical or quantitative methods (Borg Cr-10 or percentage of maximum voluntary contraction) (Borg 1982). Both exertion variables were collected and used in this study to calculate the risk using the described methods. Surface electromyography (EMG) was used to determine the muscle activity associated with maximum voluntary contraction (MVC) and job simulated exertions in static trials performed off the production line. For the board edger operator, lumber grader and trim-saw operator jobs; the flexor carpi radialis, flexor carpi ulnaris, and flexor digitorum superficialis were assessed for the flexion component and the pronator teres was evaluated for the pronation component of the board flip task. For the saw-filer job the extensor carpi radialis (ECR) and flexor carpi radialis (FCR) were assessed for the radial deviation component and the flexor carpi ulnaris (FCU) was evaluated for the ulnar deviation component of the hammering task. Only the upper extremity used to perform the primary task (task dominant upper extremity) was assessed. Electrode placement was determined by isolating the muscle in question with manual muscle testing performed by a physical therapist and placing the electrode at approximately the midpoint of the muscle belly. A Delsys Bagnoli 8 EMG system was used to record the muscle activity of all muscles assessed in each trial. Single differential bipolar electrodes with parallel bar shaped silver detection surfaces (1 cm length x 1mm width) spaced 1 cm apart were used in the experimental trails and oriented perpendicular to the muscle fibers. The data acquisition system consisted of an analog-to-digital board with a 100-kHz sampling capacity. The EMG channels (4) were sampled at 1 kHz in real time. The sampled signals were stored on a laptop computer. The EMG traces obtained during job simulated and maximum trials were full-wave rectified and linear envelope-detected from the raw EMG signals. From those processed traces, peak EMG and average EMG was measured using custom software developed by the Ergonomics Research Laboratory at the University of Alberta. Data acquisition took place during a 9 second sample to cover the entire task cycle. 2 seconds prior to the assessors instructions to begin were used to record a baseline activity and 2 seconds following the 5 second test were used to allow the subject to return to baseline values. Experimental trials were administered in random order to allow differences observed to be attributed to differences in the experimental conditions and not the order of trials. A minimum of 2 minutes rest was given to subjects between trials to prevent fatigue. Two trials were performed for each condition to allow the subject to become familiar with the task.

Maximum voluntary contraction trial. Maximum voluntary contraction (MVC) trails were performed in a location removed from the industrial process within the facility. During the MVC trials the subject was seated with the task dominant upper extremity positioned at the side and the elbow bent to 90 degrees. An isometric exertion in flexion and pronation was performed for board edger operators, lumber graders and trim-saw operators and an isometric exertion in radial and ulnar deviation was performed for saw-filers. During MVC trials the subject was instructed as follows: "When I say go, I want you to bring your force up to your maximum level over 2 seconds and hold for an additional 3 seconds or until I say stop."

Job simulated trail. Job simulated trails were performed in a location removed from the industrial process within the facility. Job simulated muscle activity was determined by having the subject maintain a representative board or hammer in a job simulated standardized static position while muscle activity was recorded. In job simulated trials the weight of the representative object was supported by the assessor until the trial was begun. After the trial was begun the weight of the representative object was given to the subject and maintained for approximately 5 seconds.

Psychophysical assessment of exertion: Following motion data collection workers were asked whether; "during the cycle were there job actions that required muscular effort of the upper limbs?" Workers were then asked to rate the actions on a scale of one to ten using the Borg CR-10 scale (Borg 1982). Borg ratings specific to the primary task of the job were used in the calculation of the ACGIH TLV, SI and OCRA assessments.

15.2.4 Data analysis

Posture: Postures required to perform the jobs were defined by randomly selecting 10 repetitions of the primary task, recording the maximum deviation in the plane of interest, and deriving the mean value for each subject. In the cases where body regions other than the forearm and wrist are considered (REBA, RULA, OCRA) the peak postural deviations observed during the observation period in the body region of interest were recorded. Peak postural deviations of body regions other than the forearm and wrist used in the calculation of the RULA, REBA and OCRA methods were confirmed via frame by frame video review and measurement with a universal goniometer.

Frequency: Repetitions performed during the sample for the board edger operator, lumber grader and trim-saw operator were determined by defining a repetition as indicated by a change in direction of motion of at least 18 degrees (setting observed to best differentiate between repetitions of primary board turn task) at the proximal radio-ulnar joint (pronation/supination). Pronation/supination was used to define repetition due to its cyclical nature in performance of the job (board turning) and clear repeated trace as recorded by the analysis system used. Repetitions performed during the saw-filer samples were determined by inspecting the radial/ulnar deviation waveform recorded by the bi-axial electrogoniometer. Radial/ulnar deviation was used to define repetition due to its cyclical nature in performance of the job (hammering saws) and clear repeated trace as recorded by the analysis system used.

Duty cycle. The percentage of the sample where the worker was active as opposed to resting was determined by defining rest periods as those periods greater than 1.2 seconds during which there was less than a 5 degree change in posture in each of the 3 planes assessed concurrently and no force applied. Rest periods were recorded, summed, and divided by total cycle time to arrive at percentage of sample performing the primary task.

Velocity and acceleration. The angular excursion and time of motion was recorded for 5 samples of the primary task subjectively assessed to be representative for 3 subjects at each facility assessed, and each job assessed, were used to calculate average velocity and acceleration values. Average velocity and acceleration were calculated by this method to enable the inertial component of the force necessary to perform the primary task to be calculated. Average values and not peak values were of interest as a "typical value" accounting for the variation in exertion required to typically perform the primary task was desired. Single and double differentiating the displacement vs. time was used to calculate velocity and acceleration respectively.

Percentage of maximum voluntary contraction. A sample of approximately 2 seconds of consistent activity from the 5 second trial was selected by reviewing the processed EMG signal of the primary agonist assessed according to the motion assessed. The average value resulting from the muscles assessed during the job simulated trials were divided by the peak EMG values obtained on the MVC comparisons to arrive at % MVC required to perform the primary task.

Dynamic force applied. Dynamic force required to turn a representative board (board edger operator, lumber grader and trim-saw operator) was calculated assuming the boards were of uniform density and the axis of rotation was along the edge of the board. Dynamic force required to hammer saws (saw-filer) was calculated assuming the center of mass of the hammer was in the middle of the hammer head. The inertial component of the force required was calculated using the average acceleration.

15.2.5 Risk assessment calculation

Methods used to calculate the risk assessments compared are based on by the primary literature describing their application (McAtamney and Corlett 1993, Moore and Garg 1997, Colombini 1998, Hignett and McAtamney2000, University of Michagin 2005). In order to enable comparison of the RULA and REBA assessments, to the other assessments examined, the risk levels of the RULA and REBA assessments were reclassified into three levels. Table 15-1 describes the scheme used to classify the risk levels compared.

Substitution of the exertion variable, calculated via quantitative means, for the exertion variable calculated based on Borg scores resulted in significantly different risk level distributions for all methods with the exception of the Strain Index. For this reason only the percentage agreement between the Strain Index calculated using %MVC and the other methods examined are described.

15.2.6 Statistical analysis

Univariate analysis with the Wilcoxin Signed Ranks test (significance level of 0.05) was performed to determine whether differences observed between risk level distributions were statistically significant. Percentage agreement between methods was assessed by comparing the risk level scores assigned by each method to the individual workers. Percentage agreement was assessed using two techniques. Percentage of agreement "at-risk" was calculated by dichotomizing risk level output into "no risk" (level 1) and at-risk (level 2 or 3) comparisons. Risk level output of the ergonomic risk assessment is used in industrial ergonomic initiatives to prioritize jobs for intervention. The implication of disagreement between methods is the inconsistent assignment of risk leading to inappropriate intervention. Given the implication of disagreement between methods it is necessary to evaluate the percentage of perfect agreement in addition to "at-risk" agreement. Percentage of "perfect" agreement was calculated by considering only those cases of exact agreement. Agreement statistics such as Kappa and the Intraclass Correlation Coefficient (ICC) were not used in this study as an insufficient number of subjects was considered to adequately populate the 3x3 table enabling valid analysis. Figure 15-1 illustrates the calculation of percentage of at-risk and perfect agreement. Both the percentage agreement, considering all workers assessed, and range of values, considering the jobs individually, are presented. The range of percentage agreement values considering the jobs individually are presented to illustrate the variation resulting from the different exposure profiles of the four jobs considered.

15.3 Results

15.3.1 Risk level comparisons

Significantly different risk level distributions (p<.05) were obtained by each methodology examined with the exception of the SI / REBA, OCRA MVC / REBA and SI / OCRA Borg distributions.

15.3.2 Percentage of agreement

Percentage of agreement: at-risk: Percentage of agreement between methods considering all workers assessed is presented in table 15-2. Ranges of values considering minimum and maximum percentage of agreement between methods specific to each job are presented in table 15-3. Generally, high levels of agreement that the jobs were at-risk existed between methods. Low percentage of agreement at-risk scores were observed between both methods of quantified ACGIH TLV calculation (exertion defined with %MVC and Borg Cr-10) and the other methods examined however. The range of percentage agreement values observed between jobs suggests the methods differ in their suitability to the exposure profiles of the jobs assessed.

Percentage of agreement: perfect agreement: Percentage of perfect agreement between risk assessment methods was observed to be lower than percentage agreement at-risk in most cases. The exception to this trend was the percentage perfect agreement observed between the ACGIH TLV methods when risk levels generated by with the %MVC criteria were compared to those generated with the Borg criteria. The exception in this case resulted from the methods agreeing no risk was present (risk level 1), and this cell not being considered in the at-risk agreement calculation. Modest levels of agreement between methods confirm risk level output will depend on the method used and a meaningful risk of disagreement between methods exists. Again, consideration of the range of values between jobs suggests the methods differ in their suitability to the exposure profiles of the jobs assessed.

15.3.3 Risk level classification

Incidence rates derived specific to the four sawmill jobs assessed in this study indicate all jobs were commonly associated with musculoskeletal injuries in the upper extremity. Given this finding all jobs may be considered at-risk. Risk levels assigned by method are presented in table 15-4. Of the methods examined the RULA and OCRA Borg methods were best able to correctly classify the jobs with correct classification rates of 99% and 84% respectively. The ACGIH TLV calculated with %MVC and the ACGIH TLV calculated with Borg scores were least able to correctly classify the jobs assessed with misclassification rates of 86% and 28% respectively.

15.4 Discussion

Valid comparison of ergonomic risk assessment methods require the methods be calculated based on quantified exposure information collected from a representative number of workers. Quantified exposure information is necessary given the large measurement error due to collecting exposure information via observation (Lowe 2004, Marshall and Armstrong 2004). Representative worker samples are necessary given the variability in exposure profiles which have been observed between workers performing the same job (Burdorf and van Reil 1996). The physical exposures required to perform the occupations examined in this study were previously described by Jones and Kumar

(2006,2007a,b,c). Variation in the physical exposures profiles observed between workers described by Jones and Kumar (2006,2007a,b,c) suggested that meaningful variation in ergonomic risk assessment scores would result from inter subject variability. No studies comparing the output of multiple ergonomic risk assessments based on quantified physical exposure information in a representative sample of workers are currently available. Table 15-4 has described the meaningful effect of variability in exposures between workers on risk level scores across multiple methods. The results of this study suggest that valid comparisons of the output of multiple ergonomic risk assessments must be based on a representative sample of workers.

In this study only high risk occupations have been examined. For this reason the reader must be cautious in interpreting the percentage agreement figures reported. Given only high exposure jobs have been examined it is relatively easy to arrive at high levels of agreement. Additional studies which compare the output of multiple risk assessment methods across a number of jobs of varying risk are necessary. Two studies are currently available which have examined the comparability of multiple risk assessment techniques across multiple jobs of varying risk (Drinkaus et al. 2003, Bao et al. 2006). Neither of these studies has based the output compared on quantified exposure information or attempted to obtain a representative sample of workers however. While this study has not examined jobs of varying levels of risk it has based its examinations of quantified exposure information in representative samples making it the most valid examination of the agreement between methods to date. Our findings of limited agreement are similar to those reported Bao et al. 2006 and opposed to those reported Drinkaus et al. 2003. Drinkaus et al. 2003 found limited agreement between the RULA and Strain Index methods (Kappa score 0.11). The Drinkaus et al. study however examined 244 assembly tasks of varying levels of risk. Given our study examined only high risk jobs conclusions regarding the agreement between the Strain Index and RULA across jobs of varying levels of risk may not be drawn. Bao et al. 2006 reports a percentage of agreement of 74.1% between the Strain Index and the ACGIH TLV. Our findings indicate a considerably lower agreement of 11% (ACGIH TLV calculated based on %MVC) and 60% (ACGIH TLV calculated based on Borg scale scores) between the ACGIH TLV and Strain Index. It is important to note however that the Bao et al. article compared the observational ACGIH TLV method and not the quantitative method used here. Importantly, the authors of the ACGIH TLV state that professional judgment should be used to recommend TLV reductions when risk factors not considered by the TLV, such as posture, are present (University of Michigan 2005). No risk level reductions due to the presence of risk factors not considered by the original models were performed in this study.

Limitations in the occupational health records used in this study prevent examinations of predictive validity. Two sources of occupational health information were reviewed prior to this study. In the first stage of review, five years of Workers Compensation Board (WCB) claims information was reviewed for the sawmill industry (Jones and Kumar 2004). Information collected by the WCB represents the finest level of standardized occupational health information available in Alberta, Canada. Two major limitations are present in the WCB dataset. First, occupational title information is available for only 64% of claims and is based on a classification system last updated in 1971. The classification system currently in use by the WCB of Alberta does not include all production position titles currently in use (Jones and Kumar 2004b). Second, information regarding the entire work force (injured and non-injured) is not collected in Alberta, Canada. The absence of information on the entire workforce prevents the calculation on incidence rates by standardized means. For the above reasons the occupational health records of each facility participating in this study were reviewed to derive the incidence rates reported (Jones and Kumar 2006,2007a,b,c). Review of facility specific occupational health information allowed specific production positions to be identified. Provision of payroll information from the facilities participating allowed person years worked to be derived and incident rates to be calculated. It is a requirement of all companies operating in Alberta, Canada to record information relating to all on-the-job injuries and reinjuries reported to the first aid room. While all facilities had this information the classification systems used by each facility was unique. The ability to identify the specific upper extremity region affected by the MSI varied by database reviewed. For this reason all injuries of a musculoskeletal nature to the upper extremity are considered in the incidence rates reported. The absence of standardized incidence information prevents the relative predictive validity of the assessment methods from being examined. Examinations of the relative predictive validity of the methods are necessary to identify the "best" method. Such examinations are important as multiple methods of limited agreement are currently in common use by practitioners to assess the risk of upper extremity MSI. Studies capable of comparing the relative predictive validity of methods are necessary as each method considers different exposure variables, classifies exposures considered by different criteria and assigns different relative roles to those criteria.

15.5 Conclusion

This study has demonstrated the limited agreement between published ergonomic risk assessment methods used to assess four at-risk sawmill jobs. Considerable variation in the ability to identify at-risk jobs at at-risk was present between methods. The implication of disagreement between methods is the incorrect assessment of risk and/or identification of problem exposures in prevention initiatives. The variation observed in risk level scores assigned between methods speaks to the lack of agreement between methods. The findings of this study emphasize the need for studies able to examine the comparative predictive validity of the methods in order to identify the current "best" model. A universally accepted and validated method of assessing risk of upper extremity MSI has yet to emerge

15.6 Acknowledgements

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Table 15-1: Risk level classification of the ergonomic risk assessment methods

	Risk index scores		
	Level 1	**Level 2**	**Level 3**
RULA	1,2	3-6	7
REBA	0	2-7	8-15
TLV MVC	1	2	3
TLV Borg	1	2	3
SI	0-3	3.1-7.0	>7.1
OCRA MVC	<.75	>.75-4.0	>4.0
OCRA Borg	<.75	>.75-4.0	>4.0

Table 15-2: Percentage of agreement. All workers

	RULA	REBA	ACGIH TLV (%MVC)	ACGIH TLV (Borg)	SI	OCRA (%MVC)	OCRA (Borg)
RULA		100 % ***(66 %)***	13 % ***(3 %)***	72 % ***(44 %)***	97 % ***(76 %)***	98 % ***(61 %)***	98 % ***(83 %)***
REBA	100 % ***(66 %)***		14 % ***(3 %)***	72 % ***(33 %)***	97 % ***(55 %)***	98 % ***(44 %)***	98 % ***(52 %)***
ACGIH TLV (%MVC)	13 % ***(3 %)***	14 % ***(3 %)***		14 % ***(36 %)***	14 % ***(7 %)***	14 % ***(8 %)***	14 % ***(7 %)***
ACGIH TLV (Borg)	72 % ***(44 %)***	72 % ***(33 %)***	14 % ***(36 %)*****		71 % ***(44 %)***	71 % ***(54 %)***	72 % ***(48 %)***
SI	97 % ***(76 %)***	97 % ***(55 %)***	14 % ***(7 %)*****	71 % ***(44 %)***		95 % ***(67 %)***	97 % ***(77 %)***
OCRA (%MVC)	98 % ***(61 %)***	98 % ***(44 %)***	14 % ***(8 %)*****	71 % ***(67 %)***	95% ***(61 %)***		98 % ***(69 %)***
OCRA (Borg)	98 % ***(83 %)***	98 % ***(52 %)***	14 % ***(7 %)*****	72 % ***(77 %)***	97% ***(83 %)***	98% ***(69 %)***	

Percentage of agreement "at-risk" no brackets. Percentage of agreement "perfect agreement" bold and italics in brackets.

Table 15-3: Percentage of agreement. Range of values between jobs

	RULA	REBA	ACGIH TLV (%MVC)	ACGIH TLV (Borg)	SI	OCRA (%MVC)	OCRA (Borg)
RULA		100 % (***14-100 %***)	0-38 % (***0-10 %***)	47-86 % (***20-55 %***)	93-100 % (***27-93 %***)	93-100 % (***27-83 %***)	93-100 % (***60-93 %***)
REBA	100 % (***14-100 %***)		0-38 % (***0-10 %***)	47-86 % (***21-48 %***)	93-100 % (***20-93 %***)	93-100 % (***20-62 %***)	93-100 % (***14-83 %***)
ACGIH TLV (%MVC)	0-38 % (***0-10 %***)	0-38 % (***0-10 %***)		0-38 % (***21-53 %***)	0-38 % (***0-10 %***)	0-38 % (***0-14 %***)	0-38 % (***0-14 %***)
ACGIH TLV (Borg)	47-86 % (***20-55 %***)	47-86 % (***21-48 %***)	0-38 % (***21-53 %***)		47-86 % (***13-52 %***)	47-86 % (***20-71 %***)	47-86 % (***27-59 %***)
SI	93-100 % (***27-93 %***)	93-100 % (***20-93 %***)	0-38 % (***0-10 %***)	47-86 % (***13-52 %***)		93-100 % (***62-80 %***)	93-100 % (***47-86 %***)
OCRA (%MVC)	93-100 % (***27-83 %***)	93-100 % (***20-62 %***)	0-38 % (***0-14 %***)	47-86 % (***20-71 %***)	93-100 % (***62-80 %***)		93-100 % (***50-83 %***)
OCRA (Borg)	93-100 % (***60-93 %***)	93-100 % (***14-83 %***)	0-38 % (***0-14 %***)	47-86 % (***27-59 %***)	93-100 % (***47-86 %***)	93-100 % (***50-83 %***)	

Percentage of agreement "at-risk" no brackets. Percentage of agreement "perfect agreement" bold and italics in brackets.

Table 15-4: Risk level classifications by risk assessment

	Safe (RL 1)	Moderate (RL 2)	At-risk (RL 3)
RULA	0 (0%)	1 (1%)	86 (99%)
REBA	0 (0%)	31(36%)	56 (64%)
ACGIH TLV (%MVC)	75 (86%)	9 (10%)	3 (3%)
ACGIH TLV (Borg)	24 (28%)	24 (28%)	39 (45%)
SI	3 (3%)	18 (21%)	66 (76%)
OCRA (%MVC)	2 (2%)	33 (38%)	52 (60%)
OCRA (Borg)	2 (2%)	12 (14%)	73 (84%)

Figure 15-1: Percentage agreement calculation.

Method 1
Risk level assigned

Method 2
Risk level assigned

	1	2	3
1	a	b	c
2	d	e	f
3	g	h	i

Perfect agreement: (a/87) + (e/87) + (i/87)
At risk agreement : (e/87) + (f/87) + (h/87) + (i/87)

15.8 References

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Phase 3 Summary: Comparison of ergonomic risk assessments

Prior to the studies represented by chapters eleven through fifteen no studies had been published which compared the output of multiple ergonomic risk assessments derived from quantified exposure measurements. The derivation of ergonomic risk assessment scores by quantified means allowed several novel examinations. First, the finding of meaningful differences in ROM, based on varying definition of posture, and the lack of association between exertion variable definitions encouraged the authors to investigate the effect of posture and exertion variable definition on risk assessment scores. Table P3-1 describes the instances where varying definition of the posture and exertion variable resulted in significantly different risk assessment scores by occupation, method and score type. The reader will note that in 100% of cases varying definition of the posture and/or exertion variable resulted in significantly different component scores. The implication of these results on the application of ergonomic risk assessments is an incorrect classification of risk or identification of problem exposures based on choice of variable definition. Phase 3 of the research project also examined the effect of variability in exposure profiles between workers within jobs on risk assessment scores. Table P3-2 summarizes coefficient of variation values derived by occupation, method and score type. Meaningful coefficient of variation values specific to component, combined component, risk index, and risk level were observed across methods and occupations examined. Observed levels of variation in risk assessment scores within jobs suggests, contrary to current practice, more than one worker assessment may required to derive risk assessment scores representative of a job. Finally, quantification of physical exposures in a representative sample of workers allowed valid comparisons of risk assessment scores between methods to be performed. Chapter 15 describes the percentage of agreement observed between methods. Based on the observed agreement between methods it may be concluded that the ergonomic risk assessment methods are indeed unique, deriving different global assessments of risk and identifying /prioritizing different specific exposures for intervention.

Table P3-1: Instances where varying posture or exertion variable definition resulted in significantly different risk assessment scores

		Board edger				Lumber grader				Saw filer				Trim saw			
		C	CC	RI	RL	C	CC	RI	RL	C	CC	RI	RL	C	CC	RI	RL
RULA	**Posture**		√	X	X		√	X	X		√	X	X		√	X	X
	Exertion																
REBA	**Posture**		√	X	X		√	√	√		√	X	X		√	X	X
	Exertion																
TLV	**Posture**																
	Exertion	√			√	√			√	√			√	√			√
SI	**Posture**	√		√	X	√		√	√	√		√	√	√		√	X
	Exertion	√		X	X	√		√	√	√		√	X	√		√	X
OCRA	**Posture**	√		√	X	√		√	√	√		√	X	√		√	X
	Exertion	√		√	√	√		√	√	√		√	√	√		√	X

Table P3-2: Range of co-efficient of variation values observed by occupation specific to method and score type.

	Board edger				Lumber grader				Saw filer				Trim saw			
	C	CC	RI	RL	C	CC	RI	RL	C	CC	RI	RL	C	CC	RI	RL
RULA	0-37%	0-29%	0%	0%	0-63%	0-38%	3%	14%	0-43%	0-30%	0%	0%	0-51%	0-23%	0%	0%
REBA	0-32%	0-33%	22%	15%	0-59%	0-53%	41%	33%	0-43%	0-37%	28%	29%	0-30%	0-17%	10%	9%
TLV	23-52%			25%	13-24%			0%	21-29%			0%	26-30%			46%
SI	20-39%		80%	19%	6-57%		77%	14%	12-42%		75%	17%	11-38%		56%	6%
OCRA	7-59%	71-89%	143%	27%	0-94%	40-81%	97%	9%	0-68%	72-107%	297%	25%	5-64%	78-94%	468%	18%

Chapter 16 – General discussion, conclusions and future work

This chapter discusses the findings of the three phases of the thesis project in the context of the research area. Special emphasis is given to the contributions of studies comprising the thesis to the research area. Future work needed to improve our ability to predict jobs at-risk of musculoskeletal injury and identify problem exposures for intervention is discussed.

16.1 Introduction

A large body of evidence supporting the role of workplace physical exposures in the causation of musculoskeletal injuries (MSIs) is now present. A number of mechanisms of injury causation based on established physiologic principles have been proposed (US Department of Health and Human Services 1997, Kumar 2001). A systematic review of epidemiologic literature examining the relationship of physical exposures to MSIs has found that in most specific MSI conditions, the risk associated with combined physical exposures is greater than the risk associated with the physical exposures alone (US Department of Health and Human Services 1997). Given it is the combination of physical exposures which are most strongly related to precipitation of MSI, a model of MSI causation is needed which is able to account for the relative role of the individual exposure variables. A valid model of MSI causation is needed to enable ergonomic practitioners to identify jobs at increased risk of MSI. Should a model of MSI causation be able to correctly identify jobs associated with high rates of MSI it follows that the model will have correctly accounted for the relative role of the physical exposures and may be used to evaluate the relative risk associated with those exposures.

Observational ergonomic risk assessments are based on models of MSI causation which consider the combined effect of physical exposures. Observation based ergonomic risk assessments are used by practicing ergonomists to gain insight into how the physical exposures of the job interact to precipitate MSIs. Observation based ergonomic risk assessments have been identified as the best method, considering the constraints of practice, by which ergonomic practitioners may establish a basis for identifying priorities for intervention (David 2005). Up to 83.1 percent of practicing professional ergonomists make use of observation based ergonomic risk assessments to assess the risk associated with manual materials handling tasks (Dempsey et al. 2005).

At present multiple risk assessment methods of unique structure have been published and the research field has been divided in the pursuit of validating competing models. As a result of the current state of disagreement there is a need to focus the research area by identifying the model of MSI causation best able to predict risk of injury and identify problem exposures. Identification of the model of injury causation "best" able to predict MSI will allow the field to move forward toward refining a model of risk prediction which accurately accounts for the role of physical exposures in the precipitation of MSIs. Refinement of the models of injury causation is needed to improve our understanding of how physical exposures may interact to precipitate MSIs. An improved understanding of the relationship between physical exposures and MSIs is needed to improve our ability to design effective prevention initiatives and reduce both the human and financial impact of MSIs.

A series of studies examining the properties of ergonomic risk assessment techniques has been performed. It is these studies which constitute the thesis of Troy Jones. The objectives of this chapter are to: 1) review the current state of ergonomic risk assessment literature to addresses the question of how multiple validated risk assessment methodologies may disagree on the structure of the model of MSI causation upon which they are based, 2) review and discuss the integrated findings of the studies comprising the thesis and their contribution to the literature, and 3) outline a progression of future studies needed to answer the questions remaining given the thesis' limitations.

The risk assessment methods compared in these studies are restricted to a selection of those methods used to assess risk of MSI in the upper extremity. The risk assessment methods considered here are the: Rapid Upper Limb Assessment (RULA, McAtamney and Corlett 1993), Rapid Entire Body Assessment (REBA, Hignett and McAtamney 2000), the quantitative version of the American Conference of Governmental Industrial Hygienists Threshold Limit Value for mono-task hand work (ACGIH TLV, University of Michigan 2005), the Strain Index (SI Moore et al. 1995), and the Concise Exposure Index (OCRA, Colombini 1998, Grieco 1998, Occhipinti 1998).

16.2 Review of current state of research area

In order to outline the process of identifying the "best" method of risk assessment it is first necessary to understand how the lack of consensus between published models of risk assessment, which have demonstrated predictive validity, is possible. It is hypothesized here that the current limited agreement between methods is primarily due to: differences in the "expert opinion" of authors, the limited ability of authors to set risk level scores and the lack of consensus in studies of predictive validity regarding the definition of morbidity.

16.2.1 Model structure

Selection of exposure variables to be considered in the risk assessment and the roles of those variables is made based upon the author's interpretation of biomechanical, physiological and epidemiologic literature. Because each author's interpretation of the literature is free to vary there is not agreement on how exposure variables such as repetition, force or posture should be weighted and how the magnitude of the interactions should be quantified in assessments of risk (Winkel and Westgaard 1992). Only in the case of the Strain Index have the authors set the weights of variables considering the findings of an experimental study in the same worker population upon which the predictive validity of the assessment was established (Moore and Garg 1994). The general lack of objective processes used by authors insetting the relative weights of variables suggests that the authors have relied on an underlying theoretical orientation to define model structure. A model structure capable of describing risk associated with MSIs in general is sought as it is not the intent of observational ergonomic risk assessments to examine risk associated with specific conditions. It is assumed that both current global theories of musculoskeletal injury causation and current theories examining the precise mechanisms of injury have been considered in selecting relevant variables and setting relative variable roles. Current global theories of MSI causation (e.g., overexertion theory, cumulative load theory) are described by Kumar 2001 and current theories of precise mechanisms of injury (e.g., Cinderella hypothesis of motor unit recruitment, reperfusion injury mechanism) are described by Forde et al. 2002.

Given the structure of the methods has been set primarily based on the opinion of the authors, it is reasonable that a level of disagreement between methods exists.

16.2.2 Determining model structure

16.2.2.1 Practical considerations

Before setting the structure of a method the authors must consider the validity of the measure and the practical implication of misclassifying the risk and the consequent output variability between evaluators.

16.2.2.1.1 False positives: The implication of misclassifying an at-risk job as safe is greater than misclassifying a safe job as at-risk. The definitions of morbidity used in studies of the association between risk output and morbidity generally err on the side of identifying safe jobs as at-risk (false positive predictions).

16.2.2.1.2 Reliability: The implication of risk output varying significantly between evaluators is of primary importance. Variability in risk assessment scores both within and between evaluators is primarily the result of measurement error due to a lack of clear definition and stringent methods of measurement of relevant variables. Authors have sought to control for measurement error resulting from exposure assessment via observation through two methods of approximation. In one method the authors adopt broad classification categories specific to each exposure variable to maximize the chance the recorded exposure will correspond to actual exposure and correlate to subsequent evaluations (e.g. RULA shoulder postures are assessed in up to 45 degree increments). The risk of using broad classifications, however, is that the groupings of exposure may not accurately capture the role of the exposure variable in the precipitation of MSI. In the second method authors recommend multiple evaluators assess each job and use consensus scores in the determination of risk. The consensus method lacks precision however, as there is no guarantee that a consensus score will be more accurate than the score of an individual evaluator. The proponents of this method have gone on to study the psychometric properties of the assessments resulting from studies using multiple evaluators and controlled exposure records. The results of this study design, while an important first step, do not reflect the limitations imposed on worksite evaluators performing assessments based on observation. Most often the ideal angle of observation, ideal focal length, ideal resolution and multiple evaluators are not available. Because of these "real world" limitations the psychometric properties resulting from such study designs cannot be assumed to reflect those attainable in worksite application. Thus both methods of approximation inherently lack accuracy and create considerable output variability between evaluators. Output variability affects both the validity and reliability of the assessment methods.

16.2.3 Model output

The structure of current ergonomic risk assessments may be roughly broken down into four levels.

1. Component scores: scores specific to body regions or physical exposure variables. Component scores are weighted by the method to reflect the relative importance of the exposure variable in the prediction model. Component scores are interpreted by the evaluator to identify and prioritize problem exposures.
2. Combined component scores: an intermediate level of interpretation where the combined role of two or more variables (e.g. posture and force) is assessed. Combined component scores may be weighted by the method to reflect the relative importance of the exposure variable in the prediction model. Component scores are interpreted by the user to identify combinations of problem exposures.
3. Risk index score: raw "risk" output.
4. Risk level or criterion score: final score representing the degree of risk associated with performance of the job.

16.2.3.1 Risk output

Worksite evaluators interpret the assessment's risk output to determine the degree of risk present in a job. Risk outputs include raw "risk index" scores and either multiple "risk levels" or a single "criterion score". Criterion or risk level scores are determined by selecting risk index cut-points which differentiate between groups of risk (e.g. no risk, moderate risk, high risk). Risk index cut-points may be set subjectively, reflecting the expert opinion of the authors and possibly a focus group, or objectively by studying the relationship between risk index scores and morbidity. The RULA, REBA and quantitative ACGIH TLV methods have used expert "opinion" to set risk levels. Risk index cut-points of the Strain Index and OCRA procedures have also been set primarily based on expert "opinion" however both methods have also considered the results of objective studies.

The criterion score of the Strain Index has been set based on the subjective inspection of relationship between risk index scores and incidence as reported by Moore and Garg (1994) however, logistic modeling of Strain Index scores and MSI incidence information has been used to support the criterion score selected (Knox and Moore 2001). The procedures used to select the risk level cut-points in the OCRA assessment are less clear. Risk level cut points originally described by Occhipinti (1998) for the OCRA procedure were selected based on a subjective review of relationship between OCRA scores and incidence of MSI. Occhipinti and Colombini (2004) report the use of an "original approach" to revise the OCRA risk level cut-points. While the use of an "original method" suggests an objective process has been used the precise method of selection used remains unclear, as an adequate description has only been published in the Italian language.

At present expert opinion has primarily been used to set criterion and risk level scores. Objective examination of the ability of the risk level cut-points selected to differentiate between levels of risk present are needed to refine the current risk index cut points that result in broad risk level scores. Refining risk index cut points is hypothesized to result in an increased ability to differentiate between levels of risk present in jobs. Comparison of the relative ability of multiple ergonomic risk assessment methods to differentiate between the level of risk present in jobs will lead to conclusions regarding the strength of the models of musculoskeletal injury causation upon which the assessments are based.

16.2.3.2 Challenges to using objective means to set risk level scores

Risk index cut-points identified by objective means are set based upon an examination of the relationship between risk index scores and incidence of MSI in multiple jobs representing different levels of risk. The relationship is studied by examining the location of each job with respect to risk index score and morbidity. The plot of risk assessment scores and morbidity information is then analyzed to differentiate between groups of jobs, where the groups reflect different levels of risk. Risk index cut-points, which define the levels of risk, are then set. The ability of the authors to differentiate between groups, and thus set cut-points, is limited by: 1) inaccuracy of exposure data collected via observation, 2) resolution of morbidity data and 3) practical considerations (described above).

16.2.3.2.1 Inaccuracy of exposure data collected via observation: Ergonomic risk assessment techniques are traditionally calculated based on exposure assessments performed by observation. A body of literature is currently available which describes the significant measurement error resulting from exposure assessment via observation (Bao et al. 2006a, Lowe et al. 2004). Inaccuracy resulting from the discrepancy between exposure measurements obtained via observation and actual exposures affects the accuracy of risk assessments in a compound manner (multiple variables considered). The "real world" limitations imposed on workplace exposure measurement by observation, combined with the literature base documenting measurement error due to observation, suggest accurate and reliable risk assessment performance, such as is required to evaluate risk index cut points, requires exposure assessment by quantified means. Quantified tools such as electromyography and electrogoniometry are the current gold standard objective measures in exposure assessment. Application of these tools within the worksite results in significantly lower levels of measurement error than are obtained in exposure assessment based on observation.

No studies prior to the studies represented by chapters 7,8,9 and10 have collected physical exposure information to be used in the calculation of multiple ergonomic risk assessments by quantified means. Due to the quantified nature of the information collected, the studies were able to examine the relationship between definitions of the posture and exertion variable definitions used interchangeably by practitioners. In each of the 4 jobs examined defining range of motion required by the peak postures, versus those required to perform the primary task only, resulted in significantly different ranges of motion. Similar to the posture variable, no association was found between measures of the exertion based on percentage of maximum voluntary contraction and psychophysical measures of exertion, in any occupation examined. The studies represented by chapters

7,8,9 and 10 were also able to describe the variability in exposures between workers within 4 unique repetitive jobs. Coefficient of variation values describing the variation in exposures observed between workers performing the same job ranged from 11 to 50% in range of motion recorded, 18 to 107% in frequency measures, 26 to 45% in exertion as determined by surface electromyography and 23 to 53% in psychophysical measures of exertion. The results of chapters 7,8,9, and 10 suggest the effect of variable definition on the predictive validity of the assessment methods must be examined due to meaningful differences observed between definitions. The results of chapters 7,8,9 and 10 also reinforce the suggestions of previous authors that individual exposure assessments are necessary to obtain exposure assessments which are representative of the population under examination (Burdorf 1996). Collection of quantified exposure information in 4 jobs allowed the subsequent calculation of 5 ergonomic risk assessment methodologies using multiple definitions of the posture and exertion variables. Novel aspects of the studies represented by chapters 11,12,13 and 14 include: describing the effect of multiple posture and exposure variable definitions on the risk outputs of 5 ergonomic risk assessments in 4 unique exposure profiles, and description of the variability in risk output scores resulting from differences in the exposure profiles of individuals within the same repetitive job. Across all risk assessment methods and jobs evaluated varying posture variable definition resulted in significantly different component or combined component scores. Defining range of motion required to perform a job by the postures required to perform the primary task versus the peak postures observed reduced risk index output by as much as 83%. Definition of the exertion variable was also observed to have a significant effect on component, combined component and risk index scores on all methods examined across all jobs. In some cases definition of the exertion variable was observed to result in significantly different risk level output. Coefficient of variation values describing the variation in risk assessment scores observed between workers performing the same job ranged from 0 to 94% in component, 0 to107% in combined component, 0 to 468% in risk index and 0-46% in risk level output across methods and jobs examined. The results of this series of studies emphasize the need for studies examining the effect of variable definition on the predictive validity of risk assessments. They also emphasizes the need for multiple worker assessments to arrive at representative risk output scores by describing the variability observed in all levels of risk output specific to 5 risk assessment methods in 4 jobs. Using figure 16-1 to illustrate the implications of these findings on our ability to set risk index cut points we see that while the true representative job score lies in the middle of the concentric circles (corresponding to sources of measurement error) a score obtained from a single worker based on an observational exposure assessment is free to fall anywhere within the circles. The implication of measurement error is a decreased ability to identify groups of workers and derive cut-points corresponding to different levels of risk by objective means (figure 16-2). The inability to set risk index cut-points by objective means has resulted in broad risk levels or single criterion scores set by subjective means. Broad risk level scores set to minimize the chance of misclassifying at-risk jobs as safe have been easily correlated to "safe" measures of morbidity. The limited ability to identify groups by objective means combined with the adoption of safe morbidity classifications has resulted in the validation of several models of MSI causation of unique structure. The validation of unique models of causation has resulted in the present state of confusion regarding the role of physical exposures in precipitation of MSI. Practically the disagreement between authors has resulted in confusion regarding the most appropriate assessment for a given application. Multiple ergonomic risk assessments have demonstrated a varying ability to identify jobs at increased risk of musculoskeletal injury in working populations despite unique model structures (Choobineh et al. 2004, Moore and Garg 1995). There is currently a lack of consensus between authors regarding the physical exposures to be considered in predicting risk and the relative role of those variables in the model of MSI precipitation upon which they are based. This lack of consensus makes examination of the comparability of risk output from multiple assessments in the same worker population(s) necessary. This necessity is emphasized by the fact up to 83.1% of practicing ergonomists make use of observational ergonomic risk assessments and the implication of disagreement between methods is the inappropriate assignment of risk and/or identification of problem exposures. Only two studies are presently available which have examined agreement between ergonomic risk assessment methods in the same worker populations (Drinkaus 2003, Bao 2006). Limitations of these studies include: exposure assessment via observation, risk output scores based on a limited number of worker assessments and the comparison of only 2 methods. The study represented by chapter 15 of the thesis has examined the agreement among 5 ergonomic risk assessment methods, based on quantified exposure information collected from a representative number of workers, in four occupations, based on multiple exposure variable definitions. The results of chapter 15 emphasize the limited agreement between some methods and thus the need for caution in application. Further, the results emphasize the need to examine the relative predictive validity of the assessments in the same population of workers based on a standardized definition of morbidity.

16.2.3.2.2 Morbidity: Morbidity may be defined as the rate of incidence of MSI conditions. In order to establish the predictive validity of an assessment method risk output is compared to a measure of morbidity. Should the assessment demonstrate an association between increasing risk output scores and increasing morbidity the assessment has established its predictive validity. Both the morbidity event and the definition of morbidity itself influence the relationship between risk output and morbidity.

Three event types have been used by past studies to define morbidity: report of discomfort consistent with MSI, recorded incidence of MSI (may include incidence of discomfort), or diagnosis of MSI based on medical examination. Inclusion of reported discomfort as an event indicating incidence of MSI must be done with caution as discomfort is a subjective experience known to vary by individual. The risk of including reported discomfort events in morbidity classifications is that false positive cases result when discomfort not indicative of MSI and/or unrelated to the job are considered in morbidity classifications. The effect of false positives in examinations of the relationship between risk assessment scores and morbidity is a reduced ability to differentiate between groups of subjects (safe and at-risk jobs). Defining events to be considered in morbidity classifications based on diagnosed conditions by health professionals minimizes the chance of false positives and is therefore the gold standard. It is for this reason that the source of morbidity information selected in the series of studies which compose the thesis first sought to draw on the standardized dataset of the WCB to describe incidence of MSIs in the at-risk occupations examined. Insufficient information was present within the WCB dataset to identify specific occupations however. Further, no information was available from any provincial or federal source which described the complete work force in sufficient detail to derive incidence rates. As a result of the limitations of the WCB dataset the occupational health records of the 4 facilities selected to participate in the project were reviewed for the five years prior to data collection. Based on the review of occupational health records 4 at-risk jobs were identified, incidence of reportable MSI events in the upper extremity in the period reviewed were defined and rates of incidence were derived using person year information. Given unique systems of data collection are used by the individual facilities the ability to compare incidence rates between facilities was restricted and the conclusions derived from such comparisons were limited to suggestive.

Morbidity has been defined a number of ways in the literature. In some cases morbidity is defined simply as the report of discomfort and predictive validity is established by studying the association between discomfort and risk assessment scores. In these cases the association is evaluated with measures of association such as the chi-square test of independence or the Fischer's exact test. In some cases the prevalence of conditions is considered and the definition of morbidity is based on the percentage of subjects reporting symptoms or diagnosed with conditions. In these cases examinations of the relationship between risk assessment scores and morbidity information are based measuring the relationship between prevalence of morbidity events in the population and risk assessment scores with prediction models such as linear and logistic regression. In these cases predictive validity is demonstrated by positive associations and high levels of explained variance.

In other cases authors define "at-risk jobs" based on a definition of morbidity related to a "trigger value". For example authors may define an "at-risk job" as one in which a single morbidity event was recorded in the period reviewed (a one incident trigger corresponds to an incident rate >0). In these cases the relationship between risk assessment scores and morbidity are examined by selecting a cut-point value (criterion score) which best differentiates between two groups defined by the morbidity classification (safe and at-risk jobs). In these cases a dichotomous risk outcome (safe or at-risk) is selected and justified by maximizing the diagnostic property of interest (e.g. sensitivity). Given the authors have dichotomized both risk output (at-risk vs. not at-risk) and morbidity outcome (positive or negative based on trigger value) predictive validity of the assessment was studied by examining the diagnostic properties of the assessment and establishing the association between risk classification and morbidity. Definition and derivation of the diagnostic properties used to evaluate predictive validity in cases where both a dichotomous risk outcome and morbidity classification are present are illustrated for the reader in figure 16-3. When predictive validity of the assessment is examined in this way the value of the criterion cut-point is influenced by the definition of morbidity. If a one incident trigger (incidence rate > 0) is selected to define morbidity the criterion cut-point will tend to be lower and the sensitivity of the test will tend to be higher at the expense of specificity. Sensitivity of the test will tend to be higher at the expense of specificity in these cases because one can expect cases where the morbidity event has occurred not as a result of the job to be included as positive cases (false positives). Practically then, a one incident trigger morbidity definition maximizes the risk assessment's ability to determine a job is "at-risk" at the expense of the risk assessments ability to find jobs which are not "at-risk". While this is a valid approach it follows that jobs which are not at increased risk of MSIs are more often identified as at-risk and exposures levels which may not be related to incidence of MSI are examined for intervention. Using a multi-incident trigger (or specified incidence rate) to define morbidity potentially decreases the sensitivity of the test and increases its specificity by correctly identifying a higher proportion of true negative cases. Accurate definition of a multi incident trigger is best done based upon an understanding of the prevalence of the conditions of interest in the occupation. If the prevalence of the conditions of interest in the non-exposed population is known the examiner is able to set the trigger value to reflect increases in prevalence hypothesized to result from work related physical exposures. Should the specified multi-incident trigger (incidence rate) underestimate the number of conditions due to workplace exposures an increased number of false positives will result decreasing the specificity of the test (ability to indicate no risk when morbidity is not present). Should the specified multi-incident trigger (incidence rate) overestimate the number of conditions due to workplace exposures an increased number of false negative values will result influencing sensitivity (ability to indicate risk when morbidity is present). The key challenge to setting the multi-incident trigger is defining the prevalence of MSI conditions in the normal population. Prevalence of MSI conditions in the normal population is often poorly understood and therefore our ability to determine the rate at which MSIs may be due to workplace physical exposures is limited. The limited ability to precisely define the prevalence of MSIs in the non exposed population justifies the use of "safe" morbidity definitions (one incident trigger).

As previously stated it was the original objective of the thesis project to determine which risk assessment method was best able to predict risk of injury in at-risk worker populations. Determination of which method or model of MSI causation was "best" involves studying the comparative predictive ability of the different risk assessment methodologies. In order to ensure such comparisons were based on accurate and representative risk assessment scores, and therefore were valid, exposures assessments were performed via quantified means in a sample of subjects which closely represented the population available. Limitations in the incidence information available prevented the analysis of predictive validity. Information describing the incidence of injuries across facilities was not available from a standardized source. Due to these limitations conclusions regarding comparisons of the ability of risk assessment methodologies to identify difference in reported incidence rates across facilities were limited to suggestive in the studies comprising chapters 11,12,13 and 14 of the thesis. Body part discomfort ratings were collected from each subject evaluated. Given information on discomfort specific to each subject was collected it is conceivable that the predictive validity of the assessments could have been examined where reported discomfort was used to define morbidity. The primary limitation to this approach however is that perception of pain/discomfort varies by individual and no measures of susceptibility (psychophysical survey, etc.) were recorded to enable assessment of whether the traits of the individual influenced reported scores. Despite these limitations reported discomfort has been used by past studies to indicate presence of MSI conditions (Werner et al. 2005). Use of reported discomfort as a morbidity event was deemed inappropriate in the context of these studies however given: no indication of worker turn over was collected enabling the impact of the "healthy worker effect" to be evaluated and only high risk occupations were examined which prevented the examination of the relationship between increasing exposure and increasing discomfort.

16.3 Selection of an appropriate ergonomic risk assessment technique

The above general discussion of the practical and methodological issues faced by the authors of risk assessment methods has discussed the need for objective studies of predictive validity seeking to refine risk assessment methods and the contribution of the studies comprising the thesis in this context. The information constraints faced by authors has resulted in the current state where the validity of multiple risk assessment methods of unique structure has been established and selection of the most appropriate assessment in a given application is difficult. No studies are currently available which have examined the comparative predictive validity of multiple assessment methods based on the same definition of morbidity in the same worker population. Such studies are needed to objectively identify the most appropriate assessment for a given application. At present therefore, selection of the most appropriate methodology requires the evaluator consider the evidence of content, predictive and concurrent validity supporting each method. Direct comparison of the validity of ergonomic risk assessments is not presently possible given the lack of studies examining the methods based on a standardized criteria.

16.3.1 Selection of an ergonomic risk assessment based on content validity

Knox and Moore (2001) have defined content validity as the concept applies to ergonomic risk assessments as follows; to be consistent with or derived from relevant physiological, biomechanical, and epidemiological principles. The content validity of ergonomic risk assessments which consider physical exposures related to MSI causation is established by the evidence base linking physical exposures to MSIs. The content validity of the methods is also established by defining model structure based on a theoretical orientation which reflects current theories of MSI injury causation. All of the assessment techniques examined in this series of studies consider physical exposures related to MSIs of the upper extremity. The number of exposures considered by the methods and the relative role of those exposures in the model of MSI causation upon which the methods are based vary however. An evaluation of the content validity of the different methods is dependent on a comparison of the level of evidence supporting the role of the exposure variables in the causation of MSI versus the exposures considered and the relative roles of those variables in the ergonomic risk assessment method. Figure 16-4 illustrates the findings of the 1997 review of epidemiologic evidence linking physical exposures to MSIs of the upper extremity and table 16-1 describes the variables considered by the risk assessment examined.

16.3.2 Selection of an ergonomic risk assessment based on predictive validity

Knox and Moore (2001) have defined predictive validity as the concept applies to ergonomic risk assessments as follows; to exhibit a reasonable ability to discriminate between adverse and non adverse exposures. External validity is an extension of predictive validity and describes the assessments ability to be applicable to a variety of circumstances of exposure (Knox and Moore 2001). The predictive validity of multiple ergonomic risk assessment methods has been established. Generally the predictive validity of the ergonomic risk assessment methods has been established by three methods: 1) examining the association between risk output and reported discomfort, 2) examining the association between dichotomized risk output and morbidity (defined by a single incident trigger) and 3) examining the association between risk output and prevalence of MSI conditions. Selection of the most appropriate ergonomic risk assessment by the worksite evaluator for the application in question requires the evaluator examine the evidence of predictive validity specific to each method. Consideration must be given to the following factors in an examination of the strength of studies of predictive validity:

1. population studied and the relationship to population of interest
2. variables examined
3. exposure assessment technique used
4. morbidity definition
5. statistical techniques
6. results

Table 16-2 describes the current studies of predictive validity by method according to the criteria above.

16.3.3 Selection of an ergonomic risk assessment based on concurrent validity

Concurrent validity of ergonomic risk assessment techniques is established by correlating the findings of one valid test to another. Should two methods have independently established predictive validity the agreement between those should be high. Possible confounders in these examinations however are differences in the populations in which the methods have demonstrated predictive validity, differences in morbidity definition used, etc. Two studies in addition to chapter 15 are currently available which have examined the agreement between methods. Drinkaus et al. (2003) compared the Strain Index and the RULA assessment and found poor agreement (Kappa score of 0.11). Bao et al. (2006b) compared the ACGIH TLV (non quantitative method) and the Strain Index and found poor to moderate agreement (weighted kappa score 0.45). The study representing chapter 15 compared the RULA, REBA, quantitative ACGIH TLV, Strain Index, and OCRA based on quantified exposure measurement. The findings of chapter 15 indicate that agreement between methods varies from moderate to low and is in some cases affected by the definition of exposure variables used. The findings of chapter 15 have been restructured according to the weighting scheme described by Bao et al. 2006b in order to enable direct comparisons and are presented in tables 16-3, 16-4, 16-5 and 16-6 corresponding to the individual occupations examined.

16.4 Conclusion

Ergonomic risk assessments are used by practicing ergonomists to identify jobs at-risk of MSI and to identify and prioritize exposures for intervention in prevention efforts. Given the current human and financial impact of MSIs and the established role of physical exposures in their precipitation research seeking to improve the ability of ergonomic risk assessments to predict injury is of paramount importance. Identification of the method and model best able to predict risk of injury in a given situation is necessary in order to improve the predicative validity of current methods. The current literature base describing the properties of ergonomic risk assessment methods has been described and the relative contributions of the studies comprising the thesis have been discussed. Limitations of the occupational health information used in the studies comprising the thesis have prevented comparative examinations of predictive validity necessary to begin to determine the best risk assessment model. Despite limitations in the occupational health information available important novel contributions to the literature base remain. The studies comprising the first phase of the thesis have described the limitations of the datasets available and set the stage for targeted improvements. The series of studies comprising the second phase of the thesis have documented the physical exposures required to perform 4 at-risk sawmill occupations have described the relationship between exposure variable definitions commonly used in the performance of ergonomic risk assessments and the degree of variability present between workers performing repetitive jobs. Results of these studies are important as they illustrate the degree of variation in risk assessment scores which may result from exposure assessment via observation and describe the variability between workers performing the same job which must be considered in determining the number of assessments required to arrive at exposure measures representative of the population. The series of studies comprising the third phase of the thesis project have examined the effect of multiple variable definitions, and the degree of variability in risk assessment output due to exposure variability between workers performing repetitive jobs. The results of the studies comprising the third phase of the project are arguably the most accurate to date given they are based on quantified exposure information collected from groups closely representing populations collected largely during job performance.

16.5 Future work

16.5.1 Occupational health information.

The absence of standardized incidence information was the single largest limiting factor encountered in these investigations. A standardized method of classifying occupations in sufficient resolution to identify specific production positions is not currently used in Alberta, Canada. Further, information regarding the composition of the entire workforce (healthy and injured) is not presently collected by any provincial or federal agency in Alberta, Canada. The inability to identify rates of incidence prevented the examination of the association between worker characteristics and injury classifications in phase 1 of the project. The inability to identify rates of MSI incidence in the occupations examined prevented examinations of the relationship between observed differences in physical exposures (between facilities within occupations and between occupations) and incidence of injury in phase 2 of the project. Such examinations are necessary to further our understanding of the causal relationship between physical exposures and incidence of injury. The inability to identify rates of MSI incidence in the occupations examined in phase 3 of the project prevented the examination of predictive validity and limited our examinations to comparisons of output. Several improvements to the existing standardized occupational health information in Alberta Canada are needed to enable the future studies necessary to evaluate and improve existing risk assessment methods. Improvements to the standardized occupational health information system include; updating the existing occupational classification scheme to one which reflects current job titles and collecting workforce exposure information based on accurate hours worked information to enable incident rate derivation.

16.5.2 Stage 1: Identification and refinement of "best" model

In order to evolve the predictive validity of ergonomic risk assessments we must first identify the existing model best able to predict risk of injury and second refine that model by studying the relative role of the quantified physical exposures in the prediction of MSI. Studies comparing multiple methods must be based on a comparison of risk output as the integrated risk output scores (risk indexes and risk levels) are the only variables common to all assessments. Identification of the risk assessment best able to predict risk of injury will require multiple ergonomic assessments be calculated based on quantified exposure assessments in a representative number of workers. Multiple jobs will need to be assessed to provide variability in risk index and morbidity scores. Variability in risk index and morbidity scores will provide the effect size sufficient for statistical procedures to differentiate between groupings of jobs corresponding to differing levels of risk. Risk groupings would be optimally defined based on an understanding of the prevalence of MSI conditions in the non exposed population and the consensus of experts as to the levels of prevalence which constitute important changes in risk. Consideration must be given to the fact that the relative role of the exposures in the precipitation of MSI may vary dependent upon the exposure profile of the job. The inclusion of multiple workers in multiple groups allows the assumption that factors other than physical exposures will have the same effect on all jobs and thus be negligible or controlled. Consideration must also be given to genetic, psychophysical and morphological factors known to influence precipitation of MSI. Superficial information on factors other than physical exposures would be collected to enable a cursory examination of the variability between groups. If the effect of factors other than physical exposures have been averaged across the jobs/subjects examined differences observed between the groups may be attributed to physical exposures.

16.5.2.1 Study requirements

- Quantified physical exposure measures: enables accurate risk assessment scores.
- Representative number of workers assessed: enables the assumption that sampled exposures are representative of actual job exposures and that the mean risk output obtained is representative of the job.
- Known population characteristics: allows rates of incidence in the exposure population to be determined which reflect the prevalence of MSIs in the non exposed population
- Morbidity events based on diagnosis of conditions by standardized criteria by health care professionals: minimizes the number of false positive morbidity events.

16.5.3 Stage 2: Model refinement

The refinement of risk assessment models will take place on three levels. On the most macro level (described above) a representative number of workers are assessed in multiple jobs, variability in MSI incidence due to factors other than physical exposures are assumed to be equal between groups, and the general role of the physical exposure variables in the precipitation of MSIs is explored. Because the variability in incidence due to individual and workplace factors is assumed to be equal between jobs, the examiner is able to assume physical exposures representative of a job are primarily responsible for incidence of injury. Having collected the above information, conclusions can be drawn regarding the relative roles of the exposure variables in the precipitation of MSIs. Further exploration of the relative role of the exposures within the model may then take place by studying the relationship between risk scores and morbidity in jobs involving the same tasks in multiple facilities where significant differences in physical exposure exist (i.e. due to job rotation etc.). This level of refinement would be accomplished by first capturing representative job demands by quantified means and recording workplace factors known to influence MSI precipitation (e.g. shift length) and then sampling occupational health records collected using standardized criteria at future time points to determine morbidity. In the second level of refinement our understanding of the relative role of exposure variables in MSI causation and the amount of exposure necessary to precipitate injury in the average worker is improved. In the second stage of refinement variability of genetic and morphologic characteristics within the groups compared are still assumed to be equal and negligible, however workplace factors known to influence incidence of injury (i.e. shifts, length of exposure etc.) are factored into the model. Conclusions are then drawn regarding the relative role of both physical exposures and workplace factors in precipitation of MSIs. In the final stage of model refinement individual workers experiencing exposures not meaningfully different (within the same facility) are assessed and the role of individual factors (i.e. genetic and morphological) in the precipitation of injury is factored into the model. This level of refinement would be accomplished by recording the physical capacities, as well as individual factors known to influence MSI precipitation (e.g. genetic, morphological, psychophysical), of workers beginning a job of known demands and following the sample. The third phase of refinement allows conclusions to be drawn regarding the effect of individual factors on precipitation of MSI given known physical exposures.

16.5.4 Refining risk assessment predictive validity by accounting for multiple tasks

Current methods may not account for the effect of multiple tasks and generally are designed for use in mono-task jobs where little if any rotation between jobs is present. Current methods (with the exception of the OCRA method) assume the peak exposure or "highest risk task" determines the risk of MSI in a job. Authors have suggested that because duration of the task and/or rest periods present in a job are related to precipitation of MSI, and only the peak exposure has been accounted for in the current models, the models should be revised to account for the cumulative effect of additional tasks (Drinkaus et al. 2005a,b). Authors of many of the risk assessment techniques report work is underway to adapt the methods to account for multiple tasks. Preliminary work has found no difference in the predictive ability of proposed multi-task models and the original models however (Drinkaus et al. 2005a,b).

Table 16-1: Physical exposures considered by method

	Physical exposures considered				
Methodology	Force	Repetition	Posture	Vibration	Combined factors
RULA	√	√	√	■	√
REBA	√	√	√	■	√
OCRA	√	√	√	√	√
SI	√	√	√	■	√
ACGIH TLV	√	√	■	■	√

Table 16-2: Studies of predictive validity

Method	Study	Population	Variables examined	Exposure assessment	Morbidity classification	Statistics used	Results	Interpretation
RULA	Massaccesi et al 2003.	77 garbage truck drivers	Ergonomic: RULA variables	Performed via observation. 1 evaluator	Discomfort as assessed by Body part discomfort survey.	Association between reported pain, aches or discomfort and corresponding RULA body part scores assessed with the $\chi 2$-test of independence.	Neck and trunk score associated with pain. Upper arm, lower arm, wrist scores not associated with pain.	RULA neck and trunk scores associated with pain in garbage truck drivers. Association between upper arm, lower arm or wrist pain and RULA scores not established in this population.
	Shuval and Donchin 2005	84 Visual display terminal workers. Computer programmers, managers, administrators and marketing specialists	Ergonomic: RULA variables Individual: Nordic questionnaire Work organizational: Nordic questionnaire (Kourinka et al. 1987) Stress: Questionnaire (Toviana, 1999).	Performed via observation. 1 evaluator. Two direct observations of each job. Mean score resulting from two observations used. Correlation between observations r =0.4-0.7.	Upper extremity musculoskeletal symptoms assessed via the Nordic questionnaire.	Predictive ability of RULA scores on hand wrist finger symptoms studied with logistic regression while calculating the odds ratio of the different categories compared to the reference category.	An increase of 1 point in the RULA risk index score increased risk of reporting hand/wrist/finger symptoms by 3.2 times. Strength of prediction model not described (r^2).	Association between the RULA score and reported symptoms established in VDT users. We don't know how predictive RULA score is of symptoms overall (what % of the variance is explained) because the factors have been considered individually.
ACGIH TLV	Latko et al. 1999. *non quantified technique	352 workers from 3 manufacturing companies	109 exposure variables analyzed: 10 anthropometry parameters, 25 medical history parameters, 5 demographic parameters, 13 psychosocial parameters, 4 tobacco use parameters, and 53 ergonomic parameters.	The HAL repetition assessment technique (Latko 1997) was performed via observation. 4 evaluators. Repetition modeled as three categories (low/medium/high) and as a continuous variable (0-10) the relationship between repetition (assessed by HAL) and the conditions was of interest.	Assessed via 4 techniques: 1) Worker questionnaire. (Cohen et al., 1983, Karasek, 1985, Franzblau et al. 1997) 2) Physical medical examination (Fine and Silverstein 1995). 3) Electrodiagnostic testing. 4) Anthropometric measurements	The relationship between the 5 health outcomes (non-specific discomfort, tendonitis, CTS symptoms only, CTS electrophysiology only, CTS symptoms and electrophysiology) and the independent variables was assessed using a three step process. 1) univariate analysis to establish relationship 2) Multiple variable logistic analyses was	Repetitiveness of work was found to be significantly associated with prevalence of reported discomfort in the wrist, hand, or fingers, tendonitis in the distal upper extremity, and symptoms consistent with carpal tunnel syndrome. An association was also found between repetitiveness of work and carpal tunnel syndrome, indicated by	Repetition as assessed by HAL was a significant term in the prediction models of reported discomfort, tendonitis and carpal tunnel syndrome. Importantly however, only repetition was evaluated and it was evaluated using the HAL assessment and not the

				Multiple workers for each job?		used to eliminate those variables within each group (anthropometry, medical history, demographic, psychosocial, tobacco, and ergonomic) which did not contribute significantly to the explained variance. 3) Multivariate logistic analyses formation of a predictive model which accounts for multiple groups of variables.	the combination of positive electro diagnostic results and symptoms consistent with carpal tunnel syndrome Strength of prediction models are not described.	quantitative assessment presented by the University of Michigan 2005.
	Franzblau et al. 2005.	908 workers from 7 different job sites. Four manufacturing operations (office furniture manufacturing, industrial container manufacturing, automobile parts manufacturing, and spark plug manufacturing) and three employers involving office or computer-related jobs (an insurance claims processing center and two government computer data entry facilities)	Ergonomic: TLV variables Individual factors: age, gender, body mass index	Observational method of Latko used to rate repetition and force required in jobs. 4 evaluators.	Presence of conditions of interest (wrist/hand/finger symptoms, elbow/forearm symptoms, wrist/hand/finger tendonitis, elbow/forearm tendonitis, carpal tunnel syndrome diagnosed by hand diagrams, CTS diagnosed by median mononeuropathy, CTS diagnosed by hand diagrams and electro diagnostic studies) assessed via 3 techniques: 1) Electro diagnostic studies 2) Self administered questionnaire 3) Physical examination.	Chi-square test was used to examine the associations. Evidence of a linear trend was assessed with the Mantel-Haenszel chi-square test of linear trend.	The prevalence of symptoms in the wrist/hand/fingers or elbow/forearm was not related to increases in TLV levels. Presence of tendonitis in the wrist/hand/fingers was not related to TLV level. Presence of elbow/forearm tendonitis was related to TLV risk level. Presence of carpal tunnel syndrome was related to TLV risk level. The sensitivity and specificity for the TLV with respect to all outcomes ranged from 0.29 to 0.59 and 0.67 to 0.73 respectively.	Association between TLV levels and elbow/forearm tendonitis and carpal tunnel syndrome were established. TLV risk level dichotomization scheme used to calculate diagnostic properties reported not described. Exposure assessment performed with observational scales not the quantitative assessment presented by the University of Michigan 2005.
	Werner et al. 2005.	501 active workers from 7 different job sites. Four manufacturing	Ergonomic: TLV variables (repetition and force), posture Individual: age,	TLV used process not described but taken to be identical to Fanzblau et al.	Upper extremity body part discomfort survey score.	The relationship of multiple variables to body part discomfort was examined.	Workers with ACGIH TLV risk levels of 2 or 3 were 2.14 times more likely to develop	Very low explained variance indicating the factors considered do not

		operations (office furniture manufacturing, industrial container manufacturing, automobile parts manufacturing, and spark plug manufacturing) and three employers involving office or computer-related jobs (an insurance claims processing center and two government computer data entry facilities)	gender, medical history, obesity, smoking history, exercise levels. Psychosocial: skill discretion decision authority, coworker support, job insecurity, job satisfaction, perceived stress. Electrophysiologic variables were also included as independent variables.	2005 (same population of workers).		Univariate analysis was followed by logistic regression modeling to determine the most predictive model for incident cases from baseline data	discomfort over time compared to the control group (O.R. 2.14). Strength of the prediction model r^2=0.14	predict the outcome well. Association between discomfort and TLV level established. Exposure assessment performed with observational scales not the quantitative assessment presented by the University of Michigan 2005.
	Gell et al. 2005	432 workers from 7 different job sites. Four manufacturing operations (office furniture manufacturing, industrial container manufacturing, automobile parts manufacturing, and spark plug manufacturing) and three employers involving office or computer-related jobs (an insurance claims processing center and two government computer data entry facilities)	Ergonomic: TLV variables (repetition and force), posture Individual: age, gender, medical history, obesity, smoking history, exercise levels. Psychosocial: skill discretion decision authority, coworker support, job insecurity, job satisfaction, perceived stress. Electrophysiologic variables were also included as independent variables.	TLV used process not described but taken to be identical to Fanzblau et al. 2005 (same population of workers).	Presence of carpal tunnel syndrome assessed via 3 techniques: 1) Electro diagnostic studies 2) Self administered questionnaire 3) Physical examination.	Multivariate logistic regression was performed using new onset of CTS as the dependent variable to create a predictive model based on data from the initial screening.	No significant difference in proportion of subjects rating above TLV level 2 between incident and control groups. Multiple logistic regression yielded a model for prediction (r2=.25) but TLV level 3 was not a significant predictor.	TLV level not observed to be a significant predictor of carpal tunnel syndrome not established with statistically significant findings in this study Exposure assessment performed with observational scales not the quantitative assessment presented by the University of Michigan 2005.
SI	Moore and Garg 1995	25 jobs within a pork processing plant Possible to examine more then one worker in the majority of cases.	Ergonomic: SI variables	Performed via observation. 1 evaluator	Review of OSHA logs and employee medical records. Specific conditions were identified by review but events included	Diagnostic properties calculated as per figure 4	Criterion value of 5 results in sensitivity of .92 and specificity of 1.0	Association between SI hazard classification and morbidity definition established in pork processing jobs.

					symptoms of non specific disorders. One incident trigger was used			
	Moore et al. 2001.	56 jobs. 28 from manufacturing (16 from chair assembly, 12 from hose and hose connector fabrication and assembly). 28 from poultry processing	Ergonomic: SI variables in addition to vibration, localized compression, cold, and use of gloves	Performed via observation. 2 raters for each job.	OSHA 200 logs, one incident trigger used.	Association between hazard classification and morbidity was assessed using Peason's chi-square or Fishers exact test. Strength of association was reported with estimated odds ratios. Diagnostic properties calculated as per figure 4	SI estimated odds ratio (108.5). Sensitivity and specificity of the SI 0.9 and 0.93 respectively	Association between SI hazard classification and morbidity definition established in in chair and hose manufacturing as well as poultry processing
	Knox and Moore 2001	28 turkey processing jobs.	Ergonomic: SI variables	Performed via observation. 2 raters for each job.	OSHA 200 logs, one incident trigger used.	Evidence of association was assessed using the likelihood ratio test for independence strength of association was reported as the odds ratio. If at least one cell had a count less than five Fishers exact test was used to determine statistical significance. Diagnostic properties calculated as per figure 4	Analysis 1 (left and right upper extremity considered separately). Relationship between morbidity and hazard assessed sig. with OR of 22 The sensitivity specificity, positive predictive value and negative predictive value were 0.86, 0.79, 0.92 and 0.65 respectively. Analysis 2 (job score represented by highest upper extremity score): OR 50 sensitivity, specificity, positive predictive value and negative predictive value were 0.91, 0.83. 0.95, and 0.71 respectively	Association between SI hazard classification and morbidity definition established in turkey processing
	Rucker and Moore 2002	28 jobs assessed 10 jobs at a hose connector plant and 18 jobs at a chair manufacturing	Ergonomic: SI variables	Performed via observation. 2 raters for each job.	OSHA 200 logs, one incident trigger used.	Evidence of association was assessed using the likelihood ratio (L.R.) test for independence strength of association	Analysis 1 (left and right upper extremity considered separately). Relationship between morbidity and hazard	Association between SI hazard classification and morbidity definition reestablished in

		plant.				was reported as the odds ratio (O.R.). If at least one cell had a count less than five Fishers exact test was used to determine statistical significance.	assessed sig. with OR of 73.3 and an LR of 21.5). The sensitivity specificity, positive predictive value and negative predictive value were 1.0, 0.84, 0.47, and 1.0 respectively. Analysis 2 (job score represented by highest upper extremity score): OR 106.6, LR 19.1 sensitivity, specificity, positive predictive value and negative predictive value were 1.0, 0.91, 0.75, and 0.75 respectively.	hose and chair manufacturing.
	Bovenzi et al 2005.	Female workers performing sanding manually or using orbital sanders (17 furniture plants: 3 groups orbital sanders A, both orbital and hand group b, hand only C) or office work	Ergonomic: SI variables in addition to vibration Individual: age, smoking drinking, height, weight, body mass index	Ergonomic variables assessed via observation. 2 raters for each job. Vibration: accelerometers	Medical interview and physical examination used to assess presence of to Raynaud's phenomenon and CTS	Univariate analysis performed to compare groups and variables significantly different were included in a multivariate regression analysis. The chi square statistic or the Fishers exact test was applied to data in the 2x2 contingency tables. Log binomial regression analysis used to assess the relationship between health complaints and individual and exposure variables.	Log-binomial regression analysis showed that the occurrence of sensorineural symptoms and CTS increased significantly with the increase of strain index score. It was estimated that the risk for CTS increased by a factor of 1.09 for each unit of increase in the strain index score. Similar results were obtained for shoulder, elbow and wrist musculoskeletal complaints.	SI scores related to CTS, and symptoms in the wrist, elbow and shoulder.
OCRA	Grieco 1998	462 workers exposed to repetitive activities of the upper limbs and 749 workers not exposed in 8 manufacturing	Ergonomic: OCRA variables	Analyzed using the methods proposed by Occ and Col 98. No further description	An index was derived equal to the total number of work related musculoskeletal disorders of the upper limb over the total	The degree of association between the morbidity scheme and the OCRA scores were examined using the simple and multiple regression functions.	A significant prediction equation was derived using simple regression equation: Y1=0.614+0.858 x1 y = Sum of all WRMSD / total number	The linear association between the % of disorders present and OCRA index is established.

		industries			number of limbs at increased risk. Disorders of the shoulder elbow wrist and hands were identified based on questionnaire (Menoni 98).		of limbs at-risk and x= exposure index (OCRA). r^2=0.88	

Table 16-3: Percentage agreement between methods: Board edger job n=14

	RULA	REBA	TLV (MVC)	TLV (Borg)	SI	OCRA (MVC)	OCRA (Borg)
RULA		93%	4%	61%	89%	71%	89%
REBA	93%		11%	61%	89%	79%	89%
*TLV (MVC)	4%	11%		43%	14%	32%	14%
*TLV (Borg)	61%	61%	43%		71%	82%	71%
SI	89%	89%	14%	71%		82%	93%
*OCRA (MVC)	71%	79%	32%	82%	82%		75%
*OCRA (Borg)	89%	89%	14%	71%	93%	75%	

Results of Jones and Kumar 2006 restructured according to weighting presented by Bao 2006 ($1-|i-j|/2$, where i and j are the indices of the rows and columns of the different methods).

* Significant differences in risk level scores were found when exertion variable was defined using %MVC vs. Borg scores

Table 16-4: Percentage agreement between methods: Lumber grader job n=29

	RULA	REBA	TLV (MVC)	TLV (Borg)	SI	OCRA (MVC & Peak posture)	OCRA (MVC and repetition average posture)	OCRA (Borg and repetition average posture)
RULA	■	57%	2%	64%	88%	95%	91%	97%
REBA	57%	■	45%	59%	62%	59%	66%	57%
*TLV (MVC)	2%	45%	■	34%	14%	3%	10%	2%
*TLV (Borg)	64%	59%	34%	■	62%	69%	69%	67%
SI	88%	62%	14%	62%	■	86%	83%	91%
*OCRA (MVC & Peak posture)	95%	59%	3%	69%	86%	■	93%	98%
*OCRA (MVC and repetition average posture)	91%	66%	10%	69%	83%	93%	■	91%
*OCRA (Borg and repetition average posture)	97%	57%	2%	67%	91%	98%	91%	■

Results of Jones and Kumar 2006 restructured according to weighting presented by Bao 2006 (1- $|i\text{-}j|$ /2, where i and j are the indices of the rows and columns of the different methods).

* Significant differences in risk level scores were found dependent upon exertion variable (%MVC vs. Borg) and/or posture variable used (peak vs. repetition average posture).

Table 16-5: Percentage agreement between methods: Saw-filer job n=15

	RULA	REBA	TLV (MVC)	TLV (Borg)	SI	OCRA (MVC)	OCRA (Borg)
RULA		90%	0%	33%	63%	60%	77%
REBA	90%		10%	43%	60%	57%	67%
*TLV (MVC)	0%	10%		67%	37%	40%	23%
*TLV (Borg)	33%	43%	67%		50%	53%	57%
SI	63%	60%	37%	50%		90%	73%
*OCRA (MVC)	60%	57%	40%	53%	90%		83%
*OCRA (Borg)	77%	67%	23%	57%	73%	83%	

Results of Jones and Kumar 2006 restructured according to weighting presented by Bao 2006 (1- $|i-j|$ /2, where i and j are the indices of the rows and columns of the different methods).

* Significant differences in risk level scores were found when exertion variable was defined using %MVC vs. Borg scores

Table 16-6: Percentage agreement between methods: Trim-saw operator job n=29

	RULA	REBA	TLV (MVC)	TLV (Borg)	SI	OCRA (MVC)
RULA		100%	24%	64%	97%	81%
REBA	100%		24%	64%	97%	81%
*TLV (MVC)	24%	24%		60%	28%	43%
*TLV (Borg)	64%	64%	60%		67%	76%
SI	97%	97%	28%	67%		81%
*OCRA (MVC)	81%	81%	43%	76%	81%	

Results of Jones and Kumar 2006 restructured according to weighting presented by Bao 2006 (1- $|i-j|$/2, where i and j are the indices of the rows and columns of the different methods).

* Significant differences in risk level scores were found when exertion variable was defined using %MVC vs. Borg score

Figure 16-1: Sources of measurement error in exposure measurement via observation.

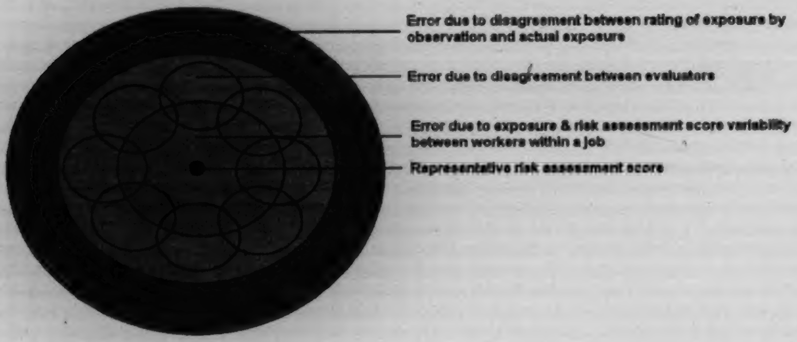

Error due to disagreement between rating of exposure by observation and actual exposure
Error due to disagreement between evaluators
Error due to exposure & risk assessment score variability between workers within a job
Representative risk assessment score

Figure 16-2: Illustration of the effect of measurement error due to observation on setting risk index cut-points.

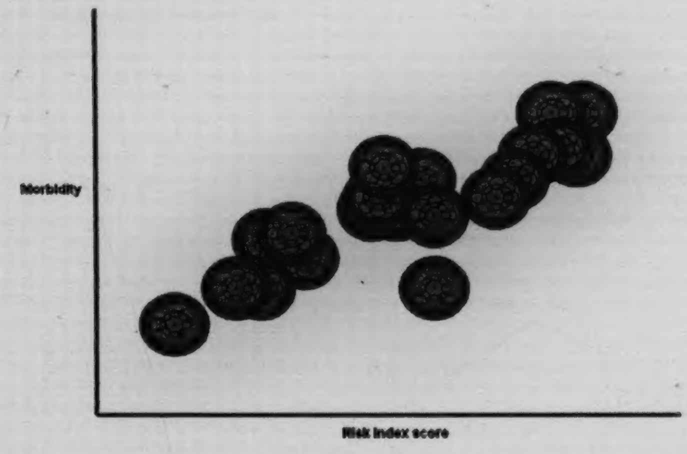


Figure 16-3: Diagnostic properties.

Risk assessment	Morbidity	
	Positive	Negative
Risk	A (True positive)	B (False positive)
No Risk	C (False negative)	D (True negative)

Sensitivity = $\frac{a}{a+c}$

Specificity = $\frac{d}{b+d}$

Positive predictive value = $\frac{a}{a+b}$

Negative predictive value = $\frac{d}{c+d}$

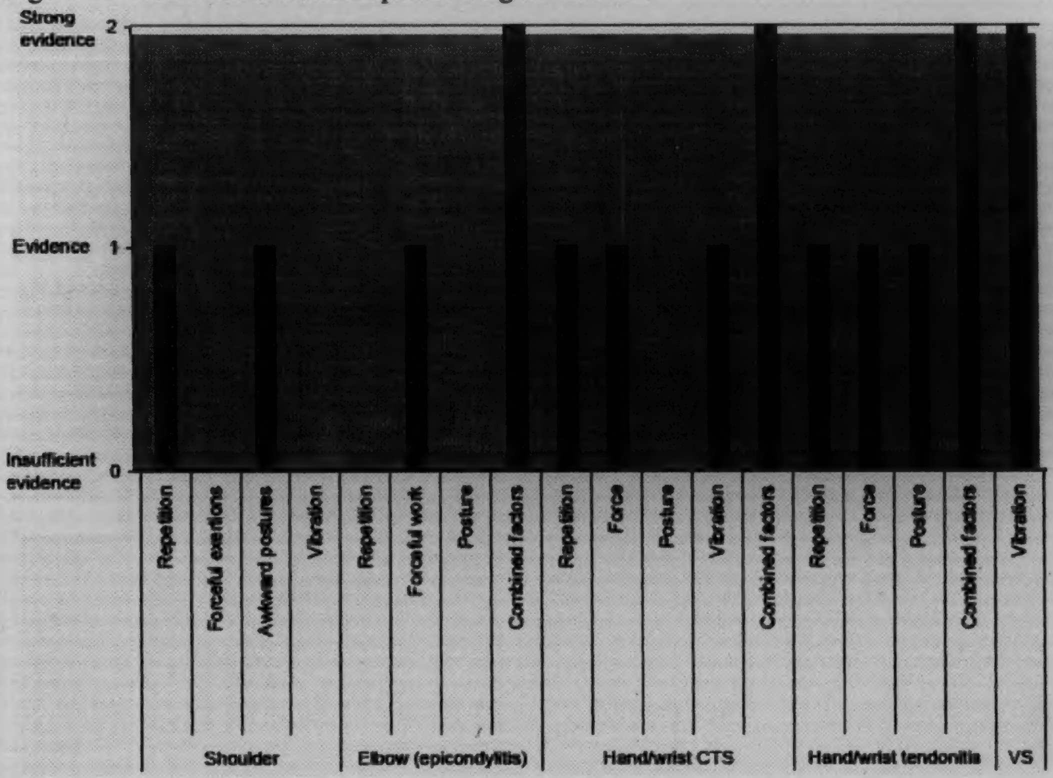
Sensitivity: The risk assessment's ability to identify the job as at-risk when morbidity is present assessed.

Specificity: The risk assessment's ability to identify the job as not at-risk when no morbidity is present.

Positive predictive value: The likelihood that the job assessed at-risk actually was associated with morbidity.

Negative predictive value: The likelihood that the job assessed as not at-risk was not associated with morbidity.

Figure 16-4: NIOSH review of epidemiologic evidence.



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